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January 8, 1998

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FEDERAL COMMUNICATIONS COMMISSION
OFFICE OF THE SECRETARY

ORIGINAL

Magalie R. Salas, Secretary
Federal Communications Commission
The Portals Building
445 12th Street, SW
TW-A325
Washington, D.C. 20554

Re: ET Docket No. 98-206

Dear Ms. Salas:

In the above-referenced Notice of Proposed Rulemaking, the Commission has asked for comment regarding spectrum sharing in the fixed satellite service between geostationary orbit ("GSO") and nongeostationary orbit ("NGSO") satellite systems. Although PanAmSat Corporation ("PanAmSat") expects to file formal comments in this proceeding, due February 16, 1999, PanAmSat is providing the accompanying engineering analysis in advance of the comment date for the convenience of the Commission. PanAmSat also is sharing this analysis with the other participants in the ITU-R Joint Task Group that is revising the provisional PFD limits for GSO/NGSO sharing that were adopted at WRC-97.

Sincerely,

Joseph A. Godles
Attorney for PanAmSat Corporation

cc: Regina Keeney
Dale Hatfield
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PROPOSED REVISION TO RESOLUTION 130 PROVISIONAL EPFD AND APFD LIMITS IN THE RESOLUTION 130 KU BANDS

The 1997 World Radiocommunication Conference (WRC-97), in order to support the implementation of non-geostationary (NGSO) fixed satellite service (FSS), approved provisional pfd limits to protect GSO FSS networks from interference originating from NGSO FSS networks operating in certain shared bands. WRC-97 Resolution 130, approved at WRC-97, recognized the provisional nature of the approval and designated ITU-R Joint Task Group (JTG) 4-9-11 to review the limits, with the intent of either their final acceptance or modification at the WRC-2000.

Annex 3 and 4 of this document propose candidate Ku-band epfd and apfd limits. These candidate limits were derived using the criteria described in ITU-R Preliminary Draft New Recommendation 4A/TEMP/66, which proposes a compact method for calculating and verifying permissible levels of interference into GSO networks from NGSO networks sharing the same spectrum.

This document proposes to verify the candidate Ku-band epfd and apfd limits derived in Annex 3 and 4 by using the 10% criteria as defined in ITU-R 1323 Recommends 3.1 and Equation 2 of this document first described in JTG 4-9-11/111 and incorporated into 4A/TEMP/66. Using the 10% criteria, the above limits will be tested against the GSO link budgets given in Annex 1 and Annex 2 of 4-9-11/TEMP/29. These link budgets were provided as a response to CR/92. Additional sensitive links are also considered here to test the proposed limits.

The analysis used to derive the final results in this document included a rigorous testing procedure where the proposed limits are tested against sensitive links. If the proposed limits account for more than 10% of the unavailability for any sensitive link than the limits failed the verification procedure. The limits were than modified until all the sensitive links pass the test.

This document uses the concept of link availability when applying the 10% criteria. Link availability is defined as the time allowance for which a given BER (or C/N value) requirement is met and is given by

$$Availability = \frac{available \cdot time}{required \cdot time} \tag{1}$$

The unavailable time is one minus the available time.

1. Summary & Conclusion: New Proposed epfd and apfd limits

Figure 1-1 shows a flowchart of the procedures used in this analysis. Methodology B′, described in Annex 3 and 4 attached, was used to derive candidate epfd and apfd limits. From Methodology B′, three epfd limit values were calculated. These values include a long term limit ($\Delta T/T$=6% not to be exceeded 99%), a short term limit, and a sync loss limit not to be exceeded at 100% of the time.

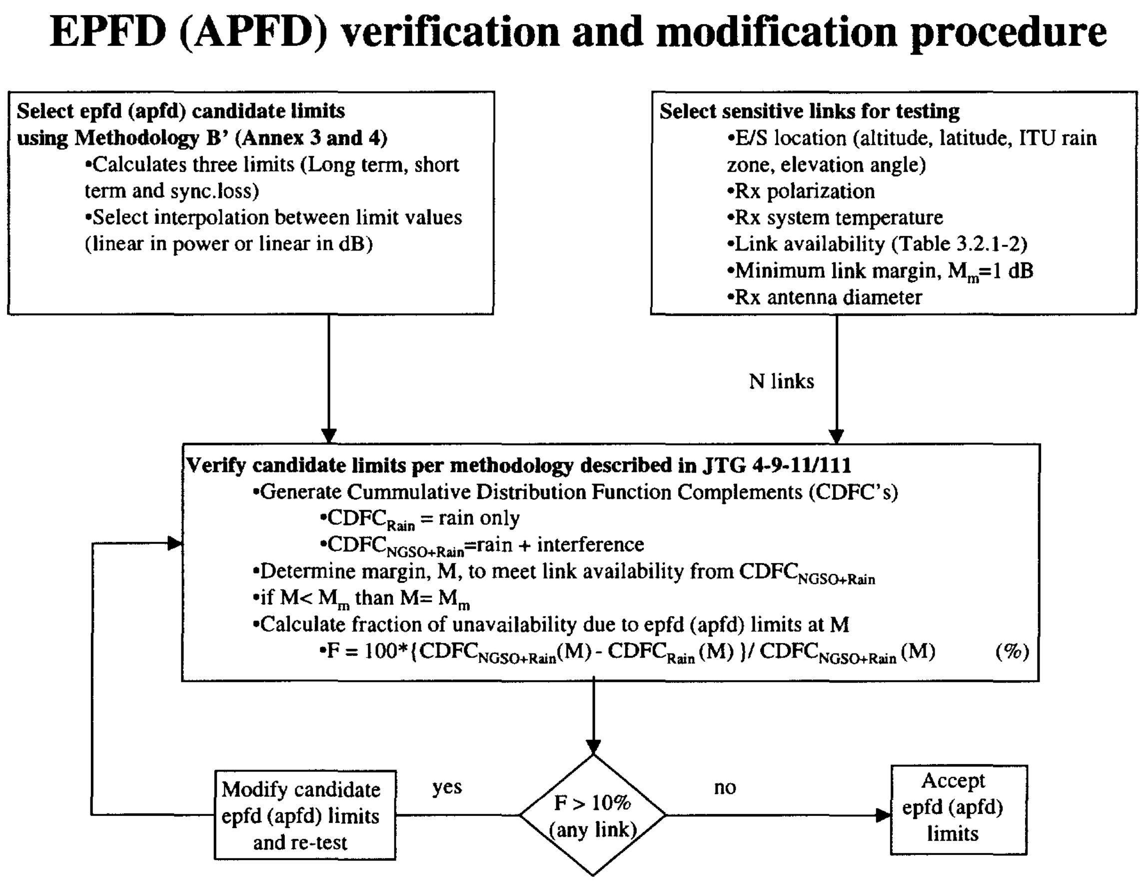


Figure 1-1: Flowchart of the epfd (apfd) verification and modification procedure.

The 10% criteria (see Section 2.1, following) was next applied to verify and modify the candidate epfd and apfd limits. The 10% criteria assumes the use of, but does not define an interpolation between epfd limit values.

Because GSO networks are globally distributed, an extended database of link scenarios was considered in this analysis. Accordingly, link budgets in Annex 1 and 2 of 4-9-11/TEMP/29 and also newly considered globally pervasive links developed for this analysis were used in the evaluation process. The aggregate epfd and apfd limits required to protect the most sensitive of this globally distributed GSO FSS link database are shown in Tables 1-1 and 1-2.

This extended data base was developed because it was felt that the link budgets in JTG 4-9-11/TEMP/29 were not fully representative of all geographic locations or the distribution of earth stations in each rain zone. Sensitive links were identified for each geographic area so that the entire possible GSO FSS infrastructure was represented when developing protection limits. As expected, the results indicate that the sensitive links are located in the driest rain zone, with the highest altitude and elevation angle.

A large number (>2700) of urban centers were examined in order to identify the sensitive links. It was determined that there are a significant number of cities with large populations distributed within dry rain zones (Figures 3.2.2-1 and 3.2.2-2). Population and number of urban centers in each rain zone are considered to be an indication of the number of earth stations that might exist in each location. Earth station elevation angles were calculated assuming the earth station and satellite were at the same longitude.

It is understood that the GSO FSS consists of a wide variety of links. Further, the links are constantly changing and evolving. The 4-9-11/TEMP/29 links do not take this into account for determining a complete understanding of what constitutes a sensitive link in the presence of NGSO interference and the 10% criteria as determined in Equation 2 (see section 2.1). A parametric study was performed as part of this analysis to ensure that the global GSO service and not just a limited set of GSO link designs are protected.

The sensitive links and the JTG 4-9-11/TEMP/29 links were assumed to operate with a minimum availability determined by the earth station antenna size. For this study it was assumed that the links had just enough margin to provide that minimum availability, unless the margin was less than 1 dB. The minimum system margin for any link was assumed to be 1 dB.

The 10% criteria requirement in section 2.1 (Equation 2) is harder to meet for lower link availabilities (See Figures 5-2 to 5-5). Minimum reasonable link availabilities were assumed for each earth station antenna size (Table 5-1). In calculating the apfd limits no power control was assumed and a link availability of 99.99% was arbitrarily chosen. Less link margin is required to operate at the lower availabilities. Higher availabilities in the links from 4-9-11/TEMP/29 don't preclude the existence (current or future) of links with lower availabilities.

Since power is a limited resource on a satellite, earth stations are assumed to operate with minimum margins to maximize the satellite capacity. Thus link margins were assumed to be just sufficient to meet the availability requirement given rain and NGSO interference. This is a common practice wherein GSO operators minimize margins so as to maximize satellite usage. Document [USJTG 4-9-11/53] provides a clear explanation of this principle.

In very low intensity rain regions this assumption of minimal margin may be considered to be unduly pessimistic. Accordingly, a minimum system margin of 1 dB was assumed for all the links regardless of the link availability requirement.

The sensitive links used the system temperatures shown in Table 3.2.1-2. These temperatures include a 20% allowance for interference from other GSO's.

Using the 10% criteria, the candidate epfd and apfd limits were verified and when necessary modified. For each link the link margin (M) that gives the desired GSO FSS network availability with rain and NGSO interference present is determined. If M is less than the 1 dB minimum margin it is set equal to 1 dB. Then with only rain fading modeled the link availability (unavailability) at the link margin M is determined. The fraction of the unavailability due to NGSO interference is calculated using Equation 2. If this fraction exceeds the 10% criteria the link fails. If any link fails the Equation 2 test than the epfd (apfd) limits are modified until all links pass.

Table 1-1 to 1-2 presents epfd and apfd limits needed to protect all of the links considered in the study for the Ku bands identified in Resolution 130. The limits chosen will adequately protect a significant majority of the GSO networks from NGSO networks sharing the same spectrum and will therefore serve as the selected bounds.

Table 1-1: Proposed Aggregate Ku-band epfd Limits.

	Provisional Single Entry EPFD Limits (WRC-97)		Proposed Aggregate NGSO system EPFD limits	
Antenna Diameter (m)	EPFD ($dBW/m^2/4$ KHz)	Percent of time not to exceed (%)	EPFD ($dBW/m^2/4$ KHz)	Percent of time not to exceed (%)
0.6	-179	99.7	-183	99
0.6	-170	99.999	-173	99.97
0.6	-170	100	-172	100
1.2			-189	99
1.2			-178	99.98
1.2			-177	100
1.8			-192	99
1.8			-181	99.99
1.8			-180	100
3	-192	99.9	-197	99
3	-186	99.97		
3	-173	99.999	-185	99.995
3	-170	100	-184	100
7			-203	99
7			-191	99.999
7			-190	100
10	-195	99.97	-206	99
10	-178	99.999	-194	99.999
10	-170	100	-193	100

Table 1-2: Proposed Aggregate Ku-band apfd Limits.

Satellite Receive Antenna	Provisional Single Entry APFD Limits (WRC-97)		Modified Aggregate NGSO system apfd limits	
Beamwidth (degrees)	APFD ($dBW/m^2/$ 4KHz)	Percent of time not to exceed (%)	APFD ($dBW/m^2/$ 4KHz)	Percent of time not to exceed (%)
1	-170	100	-186	100
2			-181	100
3			-177	100

1.1 Generic Parameters Considered for all Links

In order for there to be agreement on new epfd and apfd limits there has to be agreement or consensus on the parameters input to the 10% criteria described in Section 2.1 below. These parameters can be discussed in terms of link budgets or through other arguments. The parameters are:

1. Earth station height
2. Earth station latitude
3. Rain Zone
4. Earth station elevation angle
5. Receive antenna polarization (Circular, Vertical, or Horizontal)
6. Receive system temperature
7. Link availability
8. Minimum link margin
9. Receive antenna diameter
10. Frequency

2. Methodologies

Description of the 10% Criteria

According to Recommends 3 of ITU-R S.1323, NGSO interference can be responsible for at most 10% of the time allowance for the given BERs (or C/N values) as specified in the short-term performance objectives of the desired GSO FSS network. The 10% criteria is used to test that the epfd meets this short term requirement. In this methodology the GSO FSS link unavailability is calculated (for a range of link degradation, M) both with and without NGSO interference. The NGSO interference is acceptable if it meets the criteria shown below.

$$\boxed{\frac{(1-CDF(M)_{NGSO+Rain})-(1-CDF(M)_{Rain})}{(1-CDF(M)_{NGSO+Rain})} \leq 10\%} \qquad (2)$$

where:

CDF = Cumulative distribution function,
$CDF(M)_{Rain}$ = The probability that rain fade causes a link degradation less than M,
$CDF(M)_{NGSO+Rain}$ = The probability that the degradation from rain and NGSO interference causes a link degradation less than M.

The $CDF(M)_{Rain}$ is calculated using either the Crane or ITU rain model. The $CDF(M)_{NGSO+Rain}$ is determined by convolving the NGSO interference probability density function (pdf) with the rain pdf to form the density function representing total link degradation. This methodology assumes that rain fade and interference occur independently from one another. For downlinks the NGSO interference pdf is formed from epfd limits and convolved with the downlink rain pdf calculated from the Crane or ITU model. On the uplink the apfd limits are used to form the interference pdf and it is convolved with the uplink rain pdf. The model does not try to combine the effects of uplink and downlink rain attenuation.

The 10% criteria requires input parameters shown below.

1. Earth station height
2. Earth station latitude
3. Rain Zone
4. Earth station elevation angle
5. Receive antenna polarization (Circular, Vertical, or Horizontal)
6. Receive system temperature
7. Link availability
8. Minimum link margin
9. Receive antenna diameter
10. Frequency
11. apfd or epfd limits

Table 2.1-1: Example of Limits

Percentage time limit not exceeded (%)	Limit value ($dBW/m^2/BW$)
99.7	-179
99.999	-170
100	-170

In the calculation of the apfd limits, the receiver is on the satellite and the earth station is the transmitter. In the calculation of the epfd limits the receiver is at the earth station. The system temperature is a total system temperature and includes all noise and interference contributions in the link budget.

The formulation of the convolution assumes that when interference and rain occur at the same time the interfering signal is faded the same amount as the desired signal as shown in the derivation below.

Equation 3 below represents the downlink carrier to noise power ratio when there is rain fading and interference,

$$\boxed{\frac{C}{N_{downlink}} = \frac{Ca}{(Ts+Tr)\cdot KB + I\cdot b} = \frac{C}{\frac{1}{a}\cdot(Ts+Tr)+I\frac{b}{a}}} \tag{3}$$

where:

a = rain attenuation on desired link,
b = rain attenuation on undesired link,
Ts = total receiver noise temperature (including contributions from stages following the low noise front end),
Tr = rain noise temperature,

K=Boltzman's constant,
B=bandwidth
C = desired signal power,
I = interfering power.

The degradation due to interference and rain (Z) is the ratio of system temperature with interference and rain (denominator in Equation 3) and the system temperature without rain or interference. The resulting degradation is shown below:

$$\boxed{Z = \frac{\frac{KB}{a}\cdot(Ts+Tr)+I\frac{b}{a}}{KBTs} = \frac{1}{a}\left(1+\frac{Tr}{Ts}\right)+\frac{I}{KBTs}\frac{b}{a}} \quad (4)$$

This degradation can be separated into a component due to rain and a component due to interference as shown below:

$$\boxed{X = \frac{1}{a}\left(1+\frac{Tr}{Ts}\right)} \quad (5)$$

$$\boxed{Y = \frac{I\frac{b}{a}}{KBTs}} \quad (6)$$

where X is the degradation caused by rain and Y is the term due to interference. The analysis assumes that X and Y are independent and therefore their pdf's can be convolved. Additionally the 10% criteria assumes the fading on the undesired link (b) is the same as the fading on the desired link (a). Thus the ratio b/a = 1 and the unfaded interference density function can be used when convolving X and Y.

The program developed to implement the convolution for this analysis, was verified against the results of an alternate simulation methodology. This simulation methodology is similar to the methodology in ITU-R JTG 4-9-11/169. One advantage of the convolution, used in this analysis, is that it takes seconds to complete several hundred runs using an FFT implementation.

Methodology in Document ITU-R JTG 4-9-11/169

The methodology in document JTG 4-9-11/169 differs from the convolution procedure in document JTG 4-9-11/111. The program implements a link budget for calculating the received margin when there is rain attenuation and NGSO interference. In the case of a repeater satellite the link budget includes both up- and down-link parameters.

The program forms the joint density of the uplink and downlink rain attenuation and NGSO interference assuming that these effects are independent. The program integrates this joint density over all degradations where the link margin is less than zero and thus determines the probability of the link being degraded. As with the convolution methodology in JTG 4-9-11/111 the program calculates the probability of the link being degraded with and without the NGSO interference.

One consequence of the formulation in document JTG 4-9-11/169 may be an apparent slight increase in the link availability. Normally, link availability is calculated assuming that the uplink unavailability and downlink unavailability do not occur at the same time. Thus in practice the system availability is calculated as the product of the uplink and downlink availabilities. Integrating over the joint density of the uplink and downlink rain attenuation will result in a higher availability than taking the product of the uplink and downlink availabilities.

As argued in the last section, for the sensitive links, the contribution of the uplink to the downlink should be negligible. Therefore, results from using the methodology in document JTG 4-9-11/169 should agree with the results from using the methodology in document JTG 4-911/111. If there are differences they should become apparent by looking at the program inputs. System temperature and the transmission gains can be determined from the link budgets as described above.

3. Links

3.1. 4-9-11/TEMP/29 Annex 1 and Annex 2 Links

Circular letter CR/92 was sent out by the JTG requesting link budget information on GSO FSS sensitive links. Annex 1 and 2 of 4-9-11/TEMP29 include the link budget parameters sent to the JTG by various administrations. The Annex 1 link information includes only the minimum information required to perform the convolution calculation while Annex 2 includes complete link budget information. The approach used in this paper is to apply the convolution methodology to test the candidate epfd and apfd limits against the GSO FSS links in the Annexes. In this report the analysis was limited to transparent Ku-band satellites.

For this analysis, it was decided to not consider the link margins and availabilities provided in the link budgets. These availabilities represent specific situations and not the general situations that could exist. Since excess margin represents an unnecessary economic burden, most commercial links are designed with little or no excess.

For this analysis the calculation of satellite (uplink) and earth station temperatures are derived from the following formulas:

$$T = \begin{bmatrix} 10^{\left(C_u-\left(\frac{C}{IM}\right)_u\right)} + 10^{\left(C_u-\left(\frac{C}{TxXpol}\right)_u\right)} + 10^{N_u} + 10^{\left(C_u-\left(\frac{C}{RxXpol}\right)_u\right)} + \\ 10^{\left(C_u-\left(\frac{C}{ASI}\right)_u\right)} + 10^{\left(C_u-\left(\frac{C}{FS}\right)_u\right)} + 10^{\left(C_u-\left(\frac{C}{FR}\right)_u\right)} \end{bmatrix}$$

(7)

$$T_{E/S} = \frac{\begin{bmatrix} 10^{\left(C_d - \left(\frac{C}{IM}\right)_d\right)} + 10^{\left(C_d - \left(\frac{C}{TxXpol}\right)_d\right)} + 10^{N_d} + 10^{\left(C_d - \left(\frac{C}{RxXpol}\right)_d\right)} + \\ 10^{\left(C_d - \left(\frac{C}{ASI}\right)_d\right)} + 10^{\left(C_d - \left(\frac{C}{FS}\right)_d\right)} + 10^{\left(C_d - \left(\frac{C}{FR}\right)_d\right)} + 10^{\left(C_d - \left(\frac{C}{AdjTr}\right)_d\right)} \end{bmatrix}}{K \cdot B} \quad (8)$$

where

C_u = the power received at the satellite (dB)
$(C/IM)_u$ = transmit carrier-to-intermodulation product ratio (dB) on the uplink
$(C/TxXpol)_u$ = transmit carrier-to-transmit cross polarization isolation ratio (dB) on the uplink
N_u = uplink thermal noise (dB)
$(C/RxXpol)_u$ = carrier-to-receiver cross polarization isolation ratio (dB) on the uplink
$(C/ASI)_u$ = carrier-to-adjacent satellite interference ratio (dB) on the uplink
$(C/FS)_u$ = carrier-to-fixed service interference ratio (dB) on the uplink
$(C/FR)_u$ = carrier-to- frequency reuse isolation (dB) on the uplink
C_d = The power received at the earth station (dB)
$(C/IM)_d$ = transmit carrier-to-intermodulation product ratio (dB) on the downlink
$(C/TxXpol)_d$ = transmit carrier-to-transmit cross polarization isolation ratio (dB) on the downlink
N_d = downlink thermal noise (dB)
$(C/RxXpol)_d$ = carrier-to-receiver cross polarization isolation ratio (dB) on the downlink
$(C/ASI)_d$ = carrier-to-adjacent satellite interference ratio (dB) on the downlink
$(C/FS)_d$ = carrier-to-fixed service interference ratio (dB) on the downlink
$(C/FR)_d$ = carrier-to- frequency reuse isolation (dB) on the downlink
$(C/AdjTr)_d$ = carrier-to-adjacent transponder isolation (dB) on the downlink
K = Boltzman's constant (numerical)
B = Carrier bandwidth (Hz)

In equations 7 and 8, the adjacent satellite and fixed service interference is assumed to be unfaded by rain. This is a worst case assumption that over estimates the received system temperature.

For transparent satellites the total system temperature (T_{sys}) at the receive earth station including the contribution of the uplink is given by

$$T_{sys} = T_{E/S} + \gamma \cdot T_{sat} \tag{9}$$

where γ is the transmission gain and is equal to the numerical ratio Cu/Cd.

The satellite temperature (T_{sat}) is used when testing the apfd limits and the total system temperature (T_{sys}) is used when testing the epfd limits.

Figures 3.1-1 to 3.1-3 show a distribution of T_{sat}, T_{sys} and γ derived from the link budget information in Annex 1 and Annex 2 of 4-9-11/TEMP/29. The full link budget information can be looked up based on the carrier ID's. Carrier ID's 1 to 219 are from Annex 2 and carrier ID's 220 to 248 are from Annex 1 of 4-9-11/TEMP/29. Carrier ID's 54 to 219 were missing Earth station elevation angles and receive earth station rain zones. To complete the analysis the missing elevation angles were arbitrarily set to 20 degrees and the missing rain zones were set to ITU rain zone E.

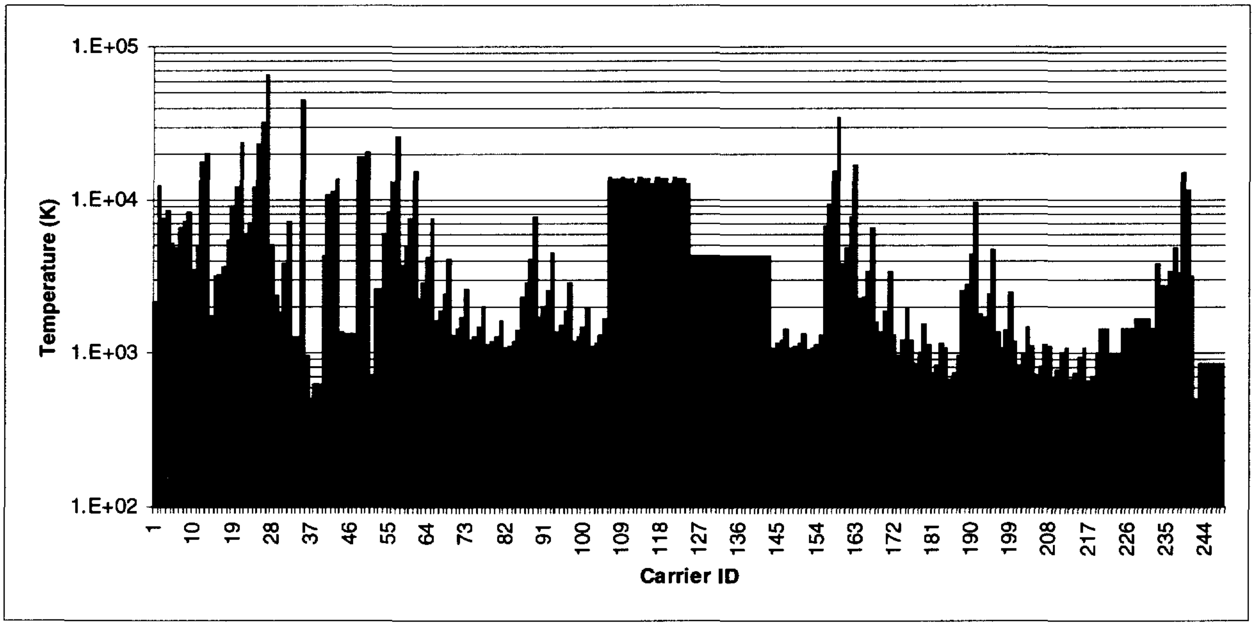


Figure 3.1-1: Ku-band Transparent Satellite Total Uplink Noise Temperatures.

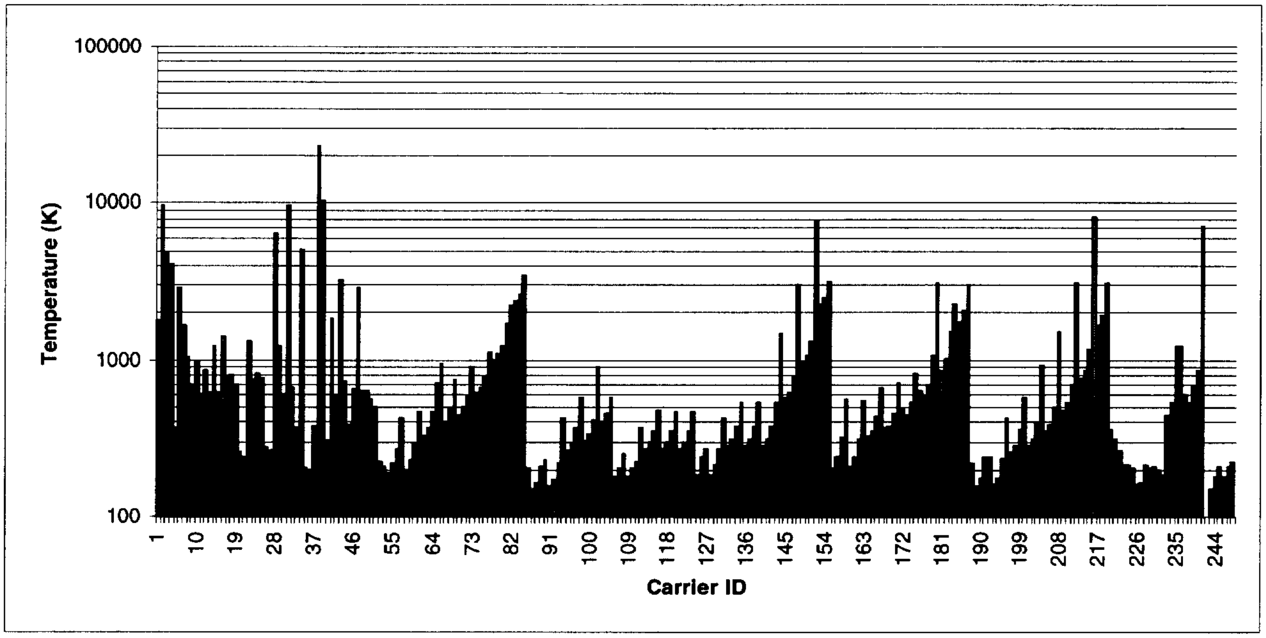


Figure 3.1-2: Ku-Band Transparent Satellite Total Downlink System Temperatures.

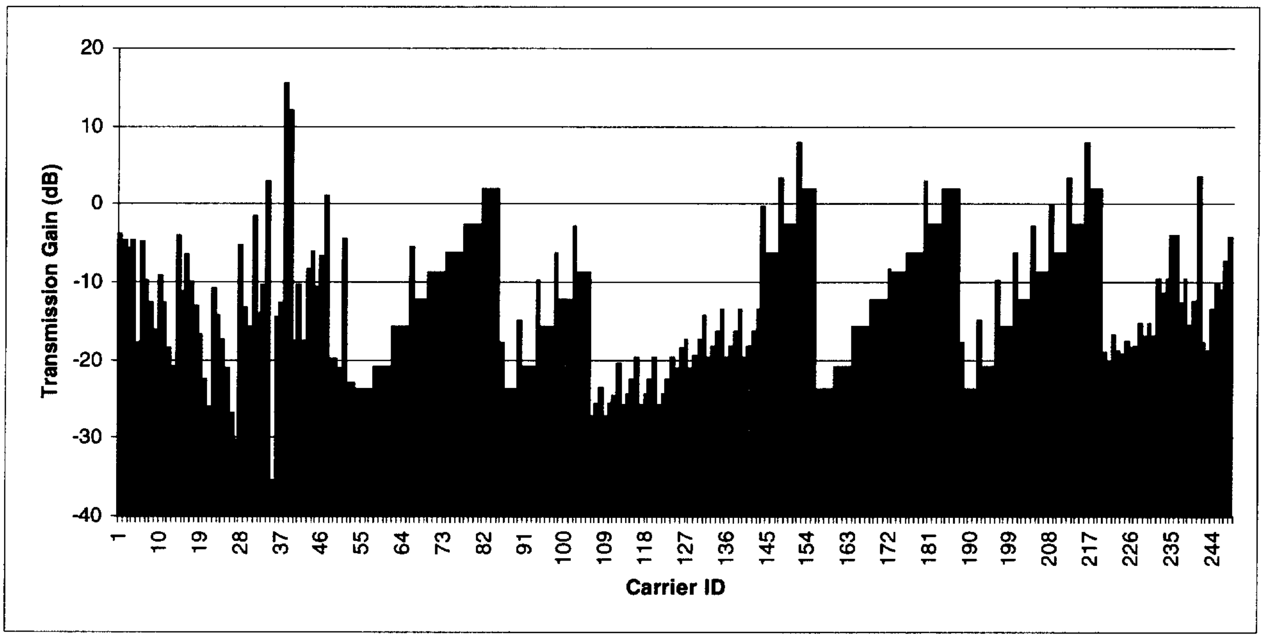


Figure 3.1-3: Ku-band Transparent Satellite Transmission Gains.

Notice that most of the transmission gains in Figure 3.1-3 are negative dB values. Thus the contribution T_{sat} to T_{sys} is reduced by γ. From Figure 3.1-2 and Figure 3.1-3 it can be seen that in general the links with the smallest γ have the smallest T_{sys}. The links with the smallest T_{sys} are the links most sensitive to NGSO interference. For the most sensitive links, those with the smallest T_{sys}, the uplink noise contribution is negligible. Additionally, most of these systems implement power control to overcome the uplink rain fades. Thus there should be no loss in accuracy, in the methodology used here, to analyze the downlink separately from the uplink.

Sensitive Link Budgets

The epfd and apfd limits need to protect sensitive links. Sensitive links are those that have minimum system temperatures and minimum rain margins. The rain margin is determined by the earth station location in terms of rain zone, altitude and elevation angle.

3.2.1 Denver Link Budget

Epfd and apfd levels given in Annex 3 and 4 of this document were derived for the most sensitive link located in Denver. The characteristics of this link are defined in Table 3.2.1-1

Table 3.2.1-1: Denver (USA) link characteristics.

Earth Station Altitude	1.61 km
Earth Station Latitude	39.73° N
Elevation Angle	43.2°
Polarization	Circular
Rain Model	ITU-R 618-5
ITU Rain Region	E
Satellite Location	101° W

This link was assumed to have minimum system temperature. The system temperatures that were used were increased 20% to account for interference from other GSO satellite systems. Table 3.2.1-2 shows the system temperatures used in the analyses.

Table 3.2.1-2: Minimum System Temperatures Used in Annexes 3 and 4 with a 20% allowance for GSO interference included.

apfd calculation	625 K
epfd calculation	188 K

3.2.2 Locations Around the World

This analysis assumes that satellite links are, in most instances, located to serve urban populations. Accordingly it is reasonable to assume that those satellite links serving urban areas located in dry climates and at higher elevations would be the most sensitive. In order to identify where sensitive links might exist throughout the world, an international data base of urban population areas located by: latitude, longitude, ITU rain zone and average altitude was created. The urban population information used to create the file was derived from data provided by the Population Division, Department of Economic and Social Affairs of the United Nations. ITU software program "Rainzone.exe" was used to identify the rain zone of each urban population center. Average altitude information was taken from topographical data available from the United States National Oceanic and Atmospheric Administration.

The resulting file provides population, location, rain zone and altitude information for over 2700 urban population center. The minimum population for classification as an urban center was limited 100,000 people (except for some few smaller island locations). The total population of the urban areas represented in the file represents about forty percent of the total world population. Annex 1 is an extract of the data base showing information for the three driest ITU rain zones (a, b and c). Figure 3.2.2-1 graphically summarizes the total of urban center populations contained in each ITU rain zone, (Figure 3.2.2-3) and Figure 3.2.2-2 graphically illustrates the number of urban areas within each ITU rain zone. The Figures and the Annex demonstrates that there are a significant number of cities with large populations distributed within these dry rain zones. It has to be presumed that these urban areas will have satellite communication requirements similar to those of the rest of the world.

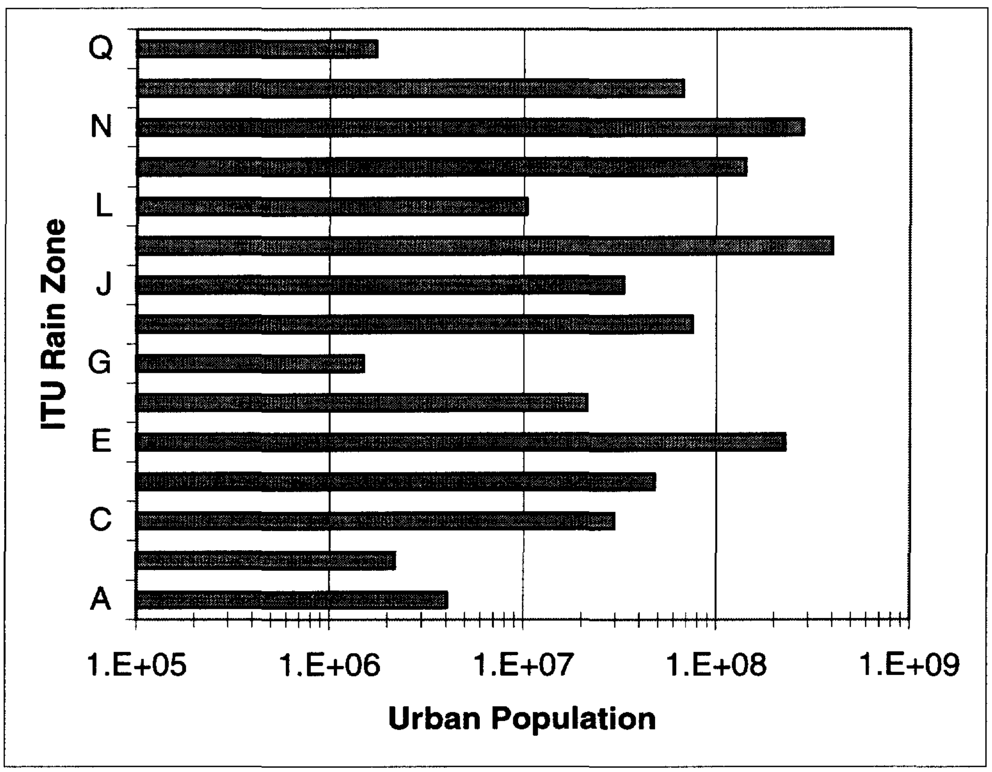


Figure 3.2.2-1: Urban Population within ITU Rain Zones.

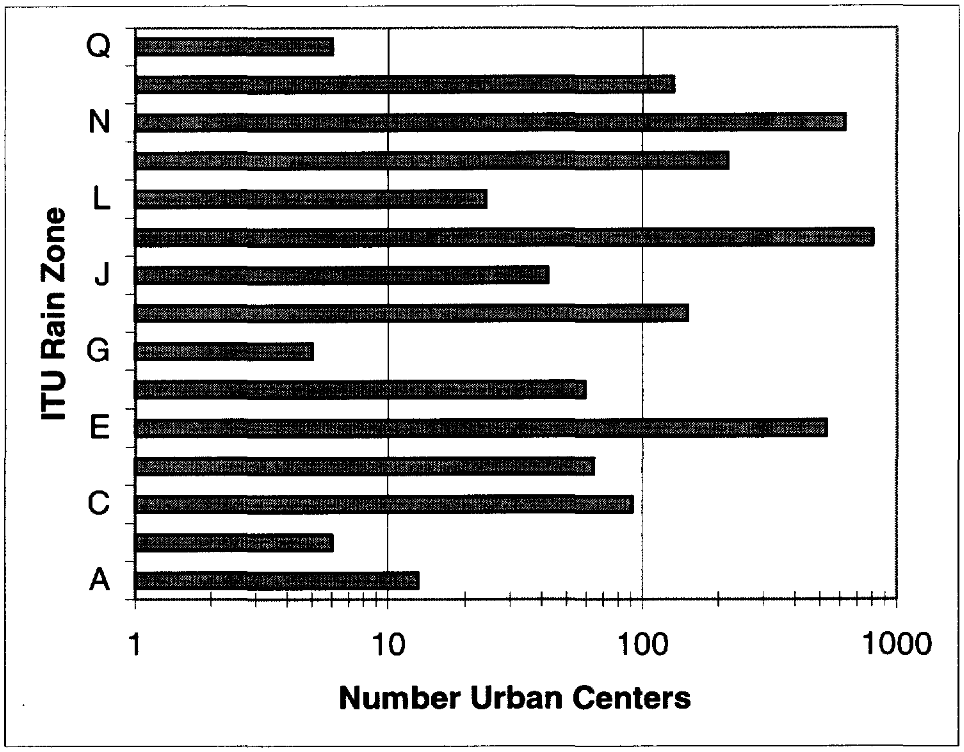


Figure 3.2.2-2: Number of Urban Centers per ITU Rain Zone.

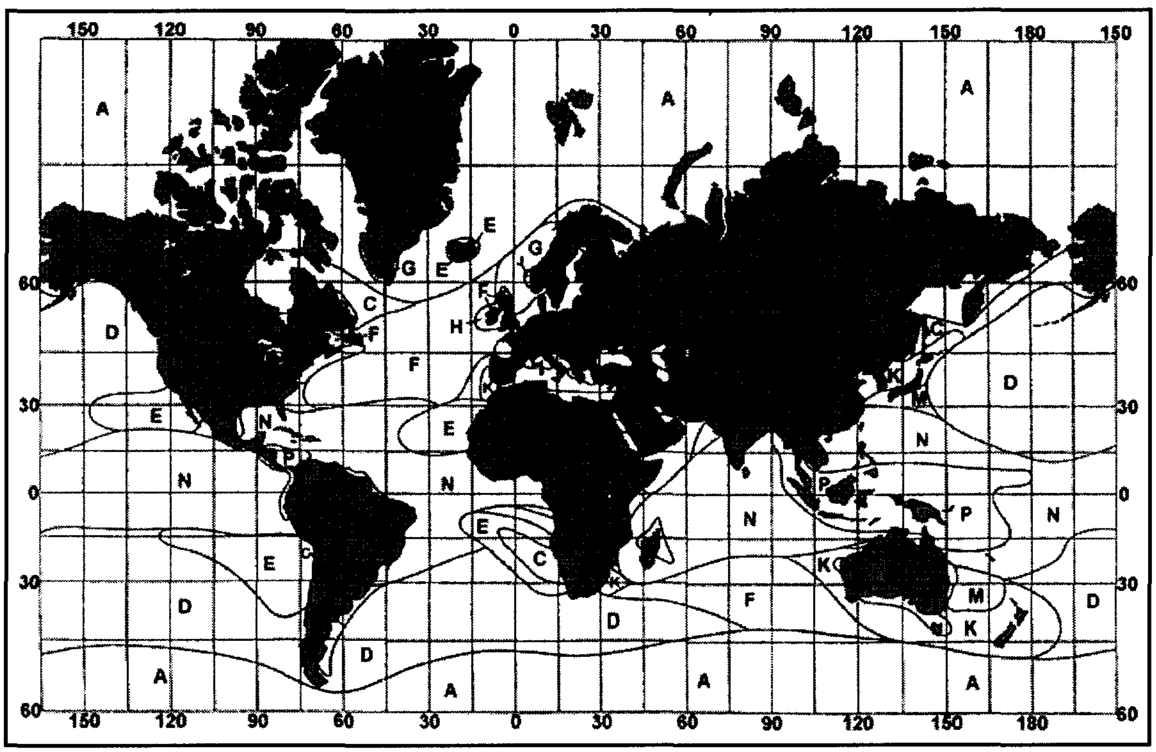


FIGURE 3.2.2-3: ITU World Rain Zones.

4.0 Methodology for Determining the Candidate EPFD and APFD Limits

The calculation of the candidate apfd and epfd limits is discussed in detail in Annex 3 and 4. The methodology uses a ΔT/T approach for calculating interference (see 4A/TEMP/66).

The calculated values for epfd and apfd limits from Annex 3 and 4 are based on the specific system parameters, representing a sensitive link, that are presented in Tables 3.2.1-1 and 3.2.1-2. The long term interference is assumed to be at 99% availability with a ΔT/T of 6%. A short term limit is calculated using Recommendation ITU-R S.1323 Methodology B. A synchronization limit, 2 dB tighter than the short term limit was also calculated (see reference 4B/TEMP/30). This limit cannot be exceeded 100% of the time.

Tables 4-1 and 4-2, show the aggregate NGSO system epfd and apfd limits proposed in Annex 3 and 4, respectively.

Table 4-1: Method B′ Ku-band candidate epfd Limits.

	Aggregate NGSO system epfd limits	
Antenna Diameter (m)	epfd ($dBW/m^2/4$ KHz)	Percent of time not to exceed (%)
0.6	-176	99
0.6	-169	99.97
0.6	-163	100
1.2	-181	99
1.2	-174	99.98
1.2	-168	100
1.8	-185	99
1.8	-176	99.99
1.8	-171	100
3	-189	99
3	-176	99.995
3	-173	100
7	-197	99
7	-181	99.999
7	-180	100
10	-200	99
10	-185	99.999
10	-183	100

Table 4-2: Method B′ Ku-band candidate apfd Limits.

Satellite Receive Antenna	Aggregate NGSO system apfd limits	
Beamwidth (degrees)	APFD (dBW/m^2/ 4kHz)	Percent of time not to exceed (%)
1	-176	100
2	-171	100
3	-167	100

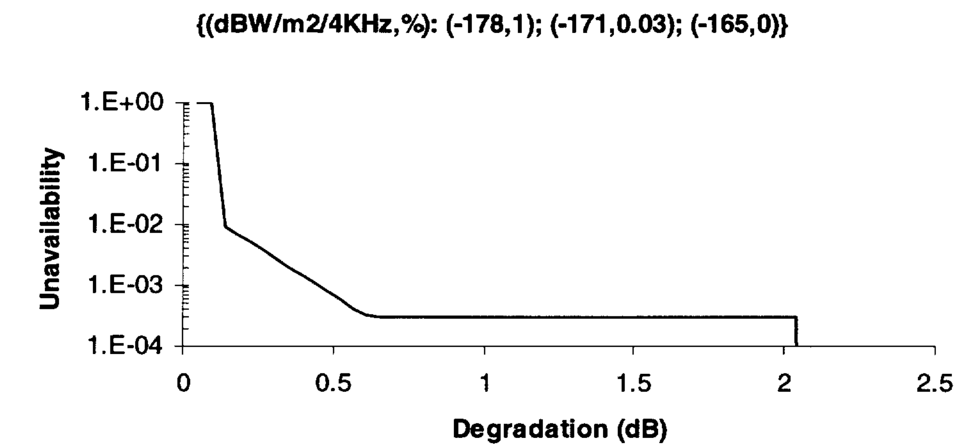
5.0

6.0 Results

In this report candidate epfd and apfd limits were tested and modified to meet the 10 % criteria in 1323 for selected GSO FSS links. Candidate epfd and apfd limits are developed in Annex 3 and 4, respectively. The apfd limits were selected so that the uplink interference does not exceed 6% of the system temperature for a 100% of the time.

Three candidate epfd limit values were calculated. These values include a long term limit (1% unavailability), a short term limit (corresponding to the operating link availability), and a (sync loss) limit, not to be exceeded at 100% of the time. The convolution methodology used to test and modify the epfd limits assumes an interpolation between the epfd limit values. In this analysis the three epfd limits were first converted to degradation. Additional points were then interpolated between the three degradation points as shown in Figure 5-1.

Figure 5-1: Cumulative Distribution Function Complement from EPFD limits



Figures 5-2 and 5-3 show example outputs using the convolution methodology. The figures show the Cumulative Distribution Function Complements (CDFC) for rain alone, and for rain plus NGSO interference (epfd limits). Additionally, the figures show the fraction of unavailability due to the NGSO interference (epfd limits) calculated using Equation 2.

In general, the figures show that it is more difficult to meet the 10% criteria for the larger unavailability times. In evaluating the links, a minimum link availability was therefore assumed. Table 5-1 shows the minimum availabilites assumed when generating epfd limits as a function of antenna size.

Table 5-1: Availabilities Assumed when Generating epfd Limits.

Antenna size (m)	Unavailability (%)	Availability (%)
0.6	0.3 %	99.7 %
1.2	0.2%	99.8%
1.8	0.1%	99.9
3	0.05%	99.95
7	0.01%	99.99%
10	0.01%	99.99%

For determining apfd limits, an availability of 99.99% (0.01% unavailability) was always assumed.

From Table 5-1 the unavailability assumed for a 0.6 m antenna was 0.003. The fraction of the unavailability due to NGSO exceeds 20% in Figure 5-2 at the 0.003 unavailability point on the rain plus NGSO curve. Thus this link failed the 10% requirement for the given epfd limits.

From the figures you can also determine how much margin (degradation) is required to meet the 10 % criteria. In Figure 5-2, the link needs a margin of approximately 2.4 dB to reduce the fraction of unavailability due to the NGSO below 10%.

Figures 5-2 and 5-3 were calculated using the interpolation shown in Figure 5-1. Notice that the discontinuity in the epfd limits produces a sharp dip in the rain plus NGSO CDFC. Figure 5-2 and 5-3 was calculated for system temperatures (Ts) equal to 188 K and 564 K, respectively. Notice that an increase in system temperature results in less margin needed to pass the 10% criteria. In Figure 5-2 with Ts=188 K the link requires a margin of about 2.4 dB while in Figure 5-3, with Ts=564 K, the link requires a margin of about 1.1 dB.

Figure 5-2: Evaluation of EPFD limits (interpol. in dB) for an E/S located in Denver (0.6 m antenna, Ts=188 K)

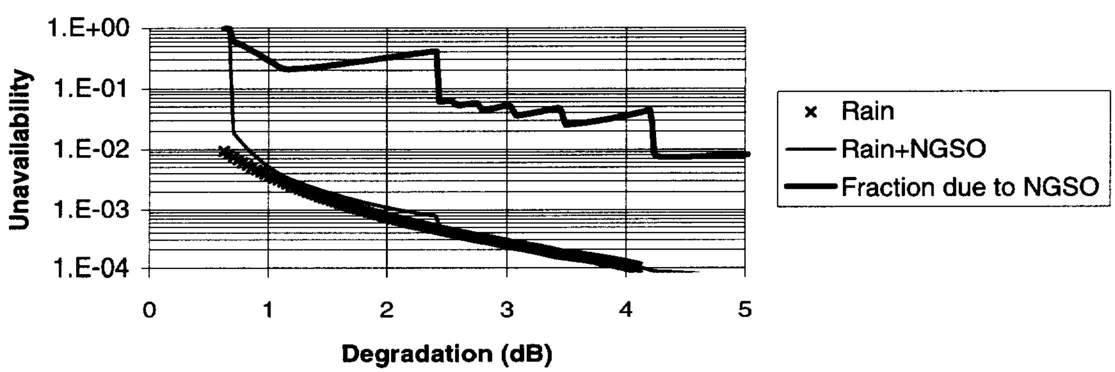
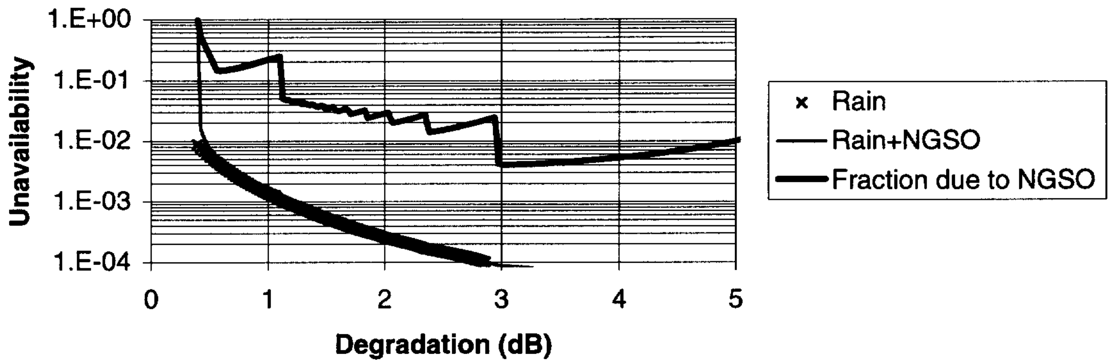


Figure 5-3: Evaluation of EPFD limits (interpol. in dB) for an E/S located in Denver (0.6 m antenna, Ts=564 K)



5.1 ITU-R JTG 4-9-11/TEMP/29 Annex 1 and Annex 2 Links

In this section the links from JTG 4-9-11/29, Annex 1 and Annex 2 are analyzed. For the Annex 2 links, the system temperatures were calculated using Equations 7, 8 and 9 and minimum availabilities in Table 5-1 were selected for each receive antenna size. The justification for setting margins to just meet the link availability is given in USJTG 4-9-11/53.

The initial limits derived in Annex 1 and Annex 2 were tested. If links failed the 10% criteria, then the limits were increased 1 dB and tested again. Testing stopped when all links passed. The tables below show only those carrier Id's that failed the 10% criteria in Equation 2. Epfd (apfd) limits are considered acceptable when all carriers meet the 10% interference limit per ITU-R 1323 (rec. 3). The limit values resulting in all carrier Id's passing are in bold in the tables. Only the limit values were varied. The epfd (apfd) percentages were kept constant.

5.1.1 Epfd results

There were 248 carrier id's (links) analyzed in this section. The distribution of receive earth station antenna sizes are shown in Table 5.1.1-1. For each antenna size there is only a limited set of links tested

Table 5.1.1-1: Distribution of receive earth station antenna sizes

Antenna size, A (m)	Number of carriers
A ≤ 0.6	55
0.6< A ≤ 1.2	48
1.2< A ≤ 1.8	31
1.8< A ≤ 3.0	45
3.0 < A ≤ 7.0	40
A >7.0	29

Table 5.1.1-2 shows the results for the 0.6 m antenna. The top of the table shows the epfd values being tested. The rest of the table shows the fraction of the unavailability due to NGSO interference for those carriers that exceeded the 10% criteria.

The first column shows the results for the initial epfd limits selected (-176,-169,-163 $dBw/m^2/4KHz$). For example, carrier ID 242 failed at this epfd limit because the unavailability due to the NGSO interference is 16.8 %. Of the 248 links, 31 failed to meet the 10% criteria. In order for all the carriers to pass the 10% criteria, the epfd limits need to be more stringent by 6 dB.

Table 5.1.1-2: Ku-band epfd limits for 0.6 m antenna (1 dB minimum margin)

% time EPFD cannot be exceeded	**EPFD (dBW/m²/4KHz)**						
99	*-176*	-177	-178	-179	-180	-181	**-182**
99.97	*-169*	-170	-171	-172	-173	-174	**-175**
100	*-163*	-164	-165	-166	-167	-168	**-169**
Carrier Id	**Fraction of unavailability due to NGSO**						
242	0.168	0.167	0.167	0.106	0.106		
15	0.365						
58	0.102	0.102	0.101				
59	0.101	0.101	0.101				
60	0.102	0.102					
61	0.105						
90	0.101	0.101	0.101				
91	0.112	0.112	0.111				
92	0.104	0.103	0.103				
93	0.106	0.106	0.106				
109	0.112	0.111	0.111				
110	0.112	0.112	0.101				
111	0.101	0.101					
112	0.102	0.102					
128	0.108	0.108	0.107				
129	0.107	0.106	0.106				
130	0.109	0.109					
131	0.101						
160	0.111	0.111					
161	0.109	0.109					
162	0.106	0.106					
163	0.103						
192	0.109	0.109					
193	0.111	0.110	0.110				
194	0.113	0.113	0.112				
195	0.110	0.110					
220	0.172	0.171	0.171	0.105	0.105		
221	0.170	0.169	0.168	0.168	0.102		
222	0.227	0.168	0.167	0.167	0.101	0.101	
223	0.227	0.170	0.170	0.169	0.107	0.107	
224	0.225	0.167	0.166	0.166	0.101	0.101	

Tables 5.1.1-3 to 5.1.1-5 show results for antenna sizes 1.2, 1.8, and 3 meters, respectively. In general the epfd limits for these antenna sizes need to be tightened more than 4 dB relative to the levels proposed in Annex 3.

Table 5.1.1-3: : Ku-band epfd limits for 1.2 m antenna (1 dB minimum margin)

% time EPFD cannot be exceeded	EPFD ($dBW/m^2/4KHz$)							
99	*-176*	-177	-178	-179	-180	-181	-182	**-183**
99.97	*-169*	-170	-171	-172	-173	-174	-175	**-176**
100	*-163*	-164	-165	-166	-167	-168	-169	**-170**
Carrier Id	**Fraction of unavailability due to NGSO**							
225	0.157	0.156	0.156					
237	0.101							
228	0.204	0.156	0.155	0.155				
229	0.205	0.157	0.156	0.156				
233	0.159	0.159						
21	0.377	0.278	0.241	0.240	0.203	0.165	0.165	
27	0.340	0.280	0.244	0.208	0.207	0.171	0.171	
35	0.215	0.163	0.162	0.162	0.105			
62	0.101							
63	0.101							
64	0.103							
94	0.101							
95	0.106							
96	0.109							
97	0.101							
113	0.105							
114	0.108							
115	0.105							
132	0.102	0.102						
133	0.104	0.103						
134	0.110							
164	0.101							
165	0.105							
197	0.109	0.109						
198	0.102	0.102						
199	0.102							
226	0.248	0.204	0.204	0.157	0.156	0.156		
227	0.248	0.204	0.203	0.155	0.155	0.155		
230	0.250	0.205	0.157	0.157	0.156	0.104		
231	0.250	0.206	0.206	0.158	0.158			
234	0.159	0.158	0.158					
238	0.159	0.158	0.158					
240	0.159	0.102						
243	0.248	0.204	0.204	0.156	0.156	0.156		

Table 5.1.1-4: : Ku-band epfd limits for 1.8 m antenna (1 dB minimum margin)

% time EPFD cannot be exceeded	EPFD (dBW/m^2/4KHz)						
99	*-185*	-186	-187	-188	-189	-190	**-191**
99.99	*-176*	-177	-178	-179	-180	-181	**-182**
100	*-171*	-172	-173	-174	-175	-176	**-177**
Carrier Id	**Fraction of unavailability due to NGSO**						
20	0.283	0.238	0.207	0.176	0.175	0.140	
26	0.278	0.238	0.207	0.174	0.173	0.138	
30	0.180	0.143					
244	0.177	0.176	0.140	0.140			

Table 5.1.1-5: Ku-band epfd limits for 3 m antenna (1 dB minimum margin)

% time EPFD cannot be exceeded	EPFD (dBW/m^2/4KHz)				
99	-189	-190	-191	-192	-193
99.995	-176	-177	-178	-179	-180
100	-173	-174	-175	-176	-177
Carrier Id	**Fraction of unavailability due to NGSO**				
245	0.132	0.132			
232	0.230	0.159	0.158	0.130	

No links failed, at the provisional epfd limits, with earth station antenna diameters greater than 3 meters.

5.1.2 Apfd results

Ku-band apfd limits were tested for satellite antenna beamwidths of 1, 2 and 3 degrees. The minimum availability used to test the 10% criteria, for all of the links, was 99.99%. In all cases the initial limits (Table 4-2) could be loosened. The new limits where all carriers passed the 10% criteria, are shown in the tables in bold. In the case of the 2 degree beamwidth, the apfd value could be loosened more than 5 dB from the initial limits. This may indicate that there aren't sensitive link budgets in the annexes of document JTG 4-9-11/TEMP/29 representative of a 2 degree satellite beamwidth.

Table 5.1.2-1: Ku-band apfd limits for 1 degree beamwidth (1 dB minimum margin)

APFD %	**APFD (dBW/m²/4KHz)**		
100	-166	-171	**-172**
Carrier ID	**Fraction of unavailability due to NGSO**		
243	0.112		
244	0.112		
245	0.112		
246	0.112		
247	0.112		
248	0.112		
242	0.141	0.108	

Table 5.1.2-2: Ku-band apfd limits for 2 degree beamwidth (1 dB minimum margin)

APFD %	**APFD** (dBW/m²/4KHz)	
100	-161	**-162**
Carrier ID	**Fraction of unavailability due to NGSO**	
234	0.100	
235	0.100	
236	0.112	
238	0.111	
241	0.109	
14	0.108	

Table 5.1.2-3: Ku-band apfd limits for 3 degree beamwidth (1 dB minimum margin)

APFD %	APFD (dBW/m²/4KHz)				
100	-156	-161	-162	-165	**-166**
Carrier ID	**Fraction of unavailability due to NGSO**				
222	0.116				
223	0.116				
224	0.116				
34	0.250	0.132	0.120	0.100	
220	0.114				
221	0.114				
225	0.114				
226	0.114				
227	0.114				
232	0.114				
38	0.142	0.113	0.111		
39	0.140	0.111	0.109		
228	0.139	0.112			
229	0.139313	0.112231			
230	0.139313	0.112231			
231	0.139313	0.112231			

5.2 Sensitive Links and New Epfd and Apfd limit

The epfd and apfd limits are designed to protect the GSO FSS. It is assumed that protection will be provided for all the most sensitive GSO FSS links. In terms of the 10% NGSO criteria, sensitive links are a function of earth station location, system margin and link availability. The most sensitive links are in dry climates, have high altitudes, high elevation angles, and operate with a minimum rain margin and link availability.

In order to develop new epfd and apfd limits the 41 most sensitive geographic locations, from the database of 2700 urban centers (Section 3.2.2), were selected. These locations were selected by sorting in order of driest rain zone, highest altitude and highest elevation angle. Information on the most sensitive links, from the database of 2700 urban centers, is contained in Annex 1. A link in Denver was also included. The Denver link was used in Annex 3 and 4, for calculating the initial epfd/apfd limits using Methodology B'.

A maximum elevation angle for the earth station was calculated, for the sensitive links, assuming that the satellite is at the same longitude as the earth station.. The minimum received temperatures in Table 3.2.1-2 and for the epfd calculation the minimum link availabilities in Table 5-1 were assumed for all the links. For determining apfd limits, an availabilities of 99.99% (0.01% unavailability) was assumed. As in the previous sections a minimum link margin of 1 dB was assumed. The sensitive links are assumed to have just enough power to meet the required link availability given rain and NGSO interference.

Annex 2 summarizes the epfd and apfd test results using the 41 most sensitive links. As in Section 5.1 each column in the Annex 2 tables tests a different epfd or apfd limit. The tables indicate the fraction of unavailability due to NGSO interference for the links that fail the 10% criteria. The last column in each table shows the epfd (apfd) limits that result in all the sensitive links passing the 10% criteria. The epfd limits are shown in Tables A2-1 to A2-7. Apfd limits are shown in Tables A2-8 to A2-10.

Table A2-1 shows the results for a GSO earth station with a 0.6 m antenna. The starting epfd limit is shown in column 1. All the sensitive links failed the 10% criteria at this epfd level. All three (long term, short term and 100% not to be exceeded) epfd limits were than varied in one dB steps, in succesive columns of the table, until all the sensitive links passed the 10% criteria.

In the last column of the table, limit values (long term, short term, and 100% not to be exceeded) were independently varied to see if the final limits could be made any looser and still have all the sensitive links pass the 10% criteria. It was determined that the long term and short limits could be loosened as shown in the last column of Table A2-1. Furthermore, this turned out to be a consistent result for all the other earth station antenna sizes as shown in Tables A2-3 to A2-7.

Table A2-2 shows the results for a GSO earth station with a 0.6 m antenna and the minimum margin relaxed from 1 dB to 2 dB. In very dry rain zones the GSO links require very little margin to operate at the required availability. Table A2-2 demonstrates the effect of adding one dB of margin to these very sensitive links. As can be seen in the last column of Table A2-2 the final epfd limits can be loosened 4 dB compared to Table A2-1.

Tables 5.2-1 and 5.2-2 show the final Ku-band epfd and apfd values required to protect all the sensitive links.

Table 5.2-1: Proposed Aggregate Ku-band epfd Limits.

	Provisional Single Entry EPFD Limits (WRC-97)		Proposed Aggregate NGSO system EPFD limits	
Antenna Diameter (m)	EPFD ($dBW/m^2/4$ KHz)	Percent of time not to exceed (%)	EPFD ($dBW/m^2/4$ KHz)	Percent of time not to exceed (%)
0.6	-179	99.7	-183	99
0.6	-170	99.999	-173	99.97
0.6	-170	100	-172	100
1.2			-189	99
1.2			-178	99.98
1.2			-177	100
1.8			-192	99
1.8			-181	99.99
1.8			-180	100
3	-192	99.9	-197	99
3	-186	99.97		
3	-173	99.999	-185	99.995
3	-170	100	-184	100
7			-203	99
7			-191	99.999
7			-190	100
10	-195	99.97	-206	99
10	-178	99.999	-194	99.999
10	-170	100	-193	100

Table 5.2-2: Proposed Aggregate Ku-band apfd Limits.

Satellite Receive Antenna	Provisional Single Entry APFD Limits (WRC-97)		Modified Aggregate NGSO system apfd limits	
Beamwidth (degrees)	APFD ($dBW/m^2/$ 4KHz)	Percent of time not to exceed (%)	APFD ($dBW/m^2/$ 4KHz)	Percent of time not to exceed (%)
1	-170	100	-186	100
2			-181	100
3			-177	100

5.3 Sensitivity Study

It has not been determined that the link budgets in JTG 4-9-11/TEMP/29 are representative of all existing and future sensitive links. For example, many of the link budgets have high availabilities and could operate with lower availabilities. Also, the link budgets are not representative of all geographic locations and there is no way to determine the number of each type of link in operation. Finally, the link budgets represent static cases and are unlikely to be representative of the vast number of link budgets in operation or of a dynamic industry whose requirements may change daily.

In order to test the breadth of representation of the 4-9-11/TEMP/29 links and to rectify some of the deficiencies in the JTG 4-9-11/TEMP/29 annexes, this analysis assumes that the number of earth stations in operation in different geographic regions will be proportional to populations in urban centers around the world. A most sensitive link is defined in each urban center and the Annex 3 epfd limits are tested. Distributions for urban centers and population versus rain zone are discussed in section 3.2.2.

Urban centers in rain zones A through M were used in the evaluations. Table 5.2-1 shows the number of urban centers in each rain zone. There were a total of 2002 urban centers used in the evaluations.

Table 5.2-1: Urban centers in each rain zone

Rain Zone	Urban Centers
A	13
B	6
C	91
D	64
E	529
F	59
G	5
H	150
J	42
K	803
L	23
M	217

5.3.1 Rain Zone Sensitivity

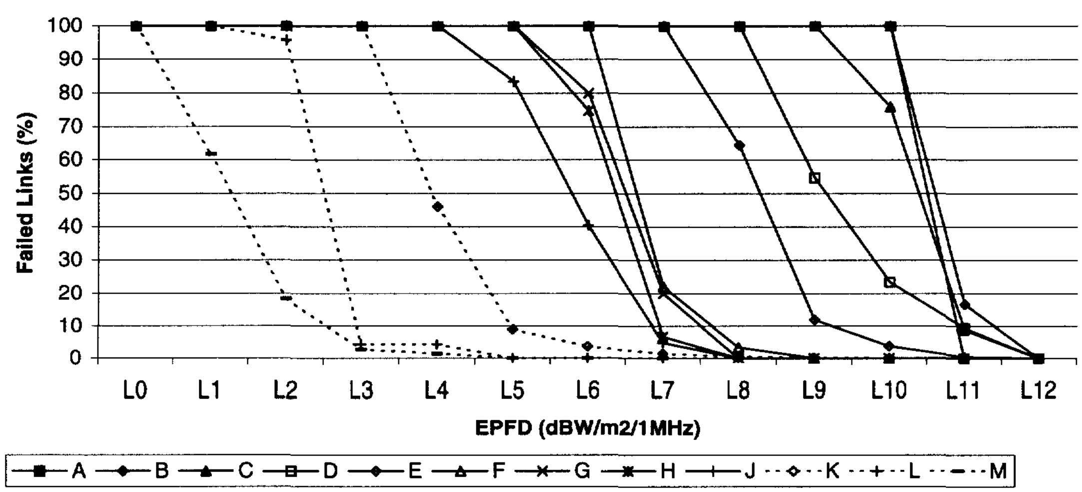
In this section the sensitivity of the epfd limits to rain zone is examined. Table 5.3-1 shows the epfd limits evaluated and should be used as a key to the results in Figures 5.3.1-1 to 5.3.1-5. The second column of the table shows the percentage of availability not to exceed. As in the previous tests the percentage the epfd limit can be exceeded was not varied. Instead, the epfd limit values were varied in one dB steps. The tests stopped when links in all urban centers passed the 10% criteria. The antennas tested were 0.6, 1.2, 1.8, 3, 7, and 10 m diameters with a system temperature of 188 K.

Table 5.3-1: Epfd limits evaluated in Figures 5.3.1-1 to 5.3.1-5.

	EPFD	EPFD (dBW/m2/4 kHz)												
Figure	%	L0	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12
	99	-171	-172	-173	-174	-175	-176	-177	-178	-179	-180	-181	-182	-183
5.3.1-1	99.97	-161	-162	-163	-164	-165	-166	-167	-168	-169	-170	-171	-172	-173
(0.6 m)	100	-160	-161	-162	-163	-164	-165	-166	-167	-168	-169	-170	-171	-172
	99	-177	-178	-179	-180	-181	-182	-183	-184	-185	-186	-187	-188	-189
5.3.1-2	99.98	-166	-167	-168	-169	-170	-171	-172	-173	-174	-175	-176	-177	-178
(1.2 m)	100	-165	-166	-167	-168	-169	-170	-171	-172	-173	-174	-175	-176	-177
	99	-180	-181	-182	-183	-184	-185	-186	-187	-188	-189	-190	-191	-192
5.3.1-3	99.99	-169	-170	-171	-172	-173	-174	-175	-176	-177	-178	-179	-180	-181
(1.8 m)	100	-168	-169	-170	-171	-172	-173	-174	-175	-176	-177	-178	-179	-180
	99	-185	-186	-187	-188	-189	-190	-191	-192	-193	-194	-195	-196	-197
5.3.1-4	99.995	-173	-174	-175	-176	-177	-178	-179	-180	-181	-182	-183	-184	-185
(3 m)	100	-172	-173	-174	-175	-176	-177	-178	-179	-180	-181	-182	-183	-184
	99	-191	-192	-193	-194	-195	-196	-197	-198	-199	-200	-201	-202	-203
5.3.1-5	99.999	-179	-180	-181	-182	-183	-184	-185	-186	-187	-188	-189	-190	-191
(7 m)	100	-178	-179	-180	-181	-182	-183	-184	-185	-186	-187	-188	-189	-190
	99	-194	-195	-196	-197	-198	-199	-200	-201	-202	-203	-204	-205	-206
5.3.1-6	99.999	-182	-183	-184	-185	-186	-187	-188	-189	-190	-191	-192	-193	-194
(10 m)	100	-181	-182	-183	-184	-185	-186	-187	-188	-189	-190	-191	-192	-193

Figure 5.3.1-1 shows the result of the epfd evaluation for a 0.6 m antenna with a system temperature of 188 K and a one dB minimum margin. The figure indicates the percentage of cities failing the 10% NGSO requirement for each epfd limit and as a function of rain zone. As expected the more sensitive links are in the dryer rain zones. An epfd level equal to L12 is required to protect all urban centers in rain zone A and B. Notice that there is about a seven dB spread for full protection of links in rain zone M compared to rain zone A.

Figure 5.3.1-1: Percentage of Links Failing the 10% Criteria (0.6 m antenna, Tsys=188 K, 1 dB min margin)



Figures 5.3.1-2, 5.3.1-3 and 5.3.1-4 .show the evaluation results for a 1.2, 1.8 and 3 m antenna respectively. In general the curves show the same trends as was seen in Figure 5.3.1-1. Again

there is about a seven dB spread between protection of all cities in rain zone M and all cities in rain zone A.

Figure 5.3.1-2: Percentage of Links Failing the 10% Criteria (1.2 m antenna, Tsys=188 K, 1 dB min margin)

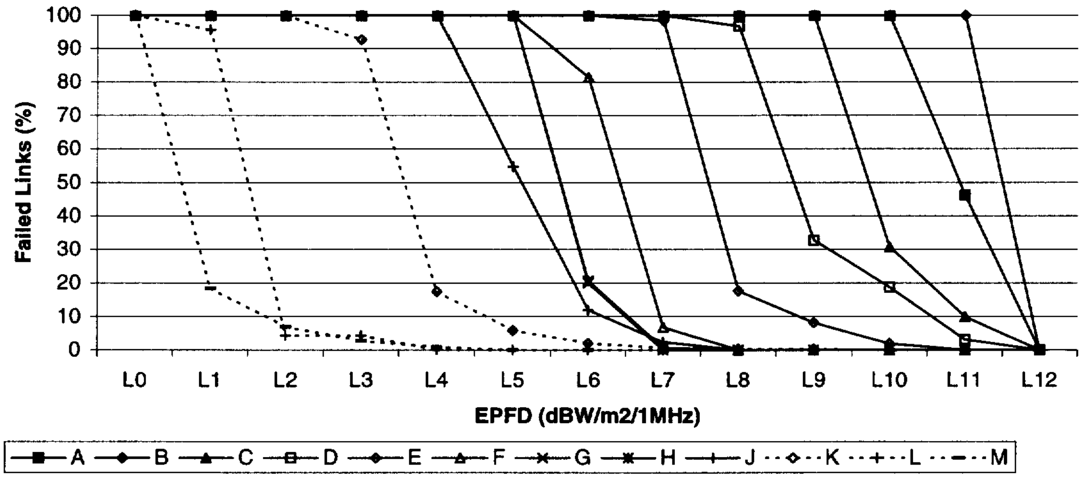
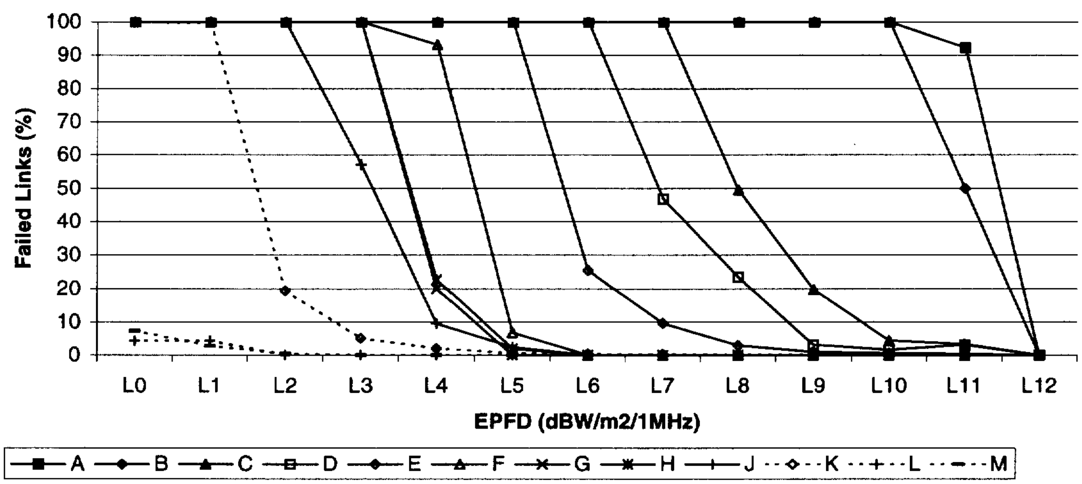


Figure 5.3.1-3: Percentage of Links Failing the 10% Criteria (1.8 m antenna, Tsys=188 K, 1 dB min margin)



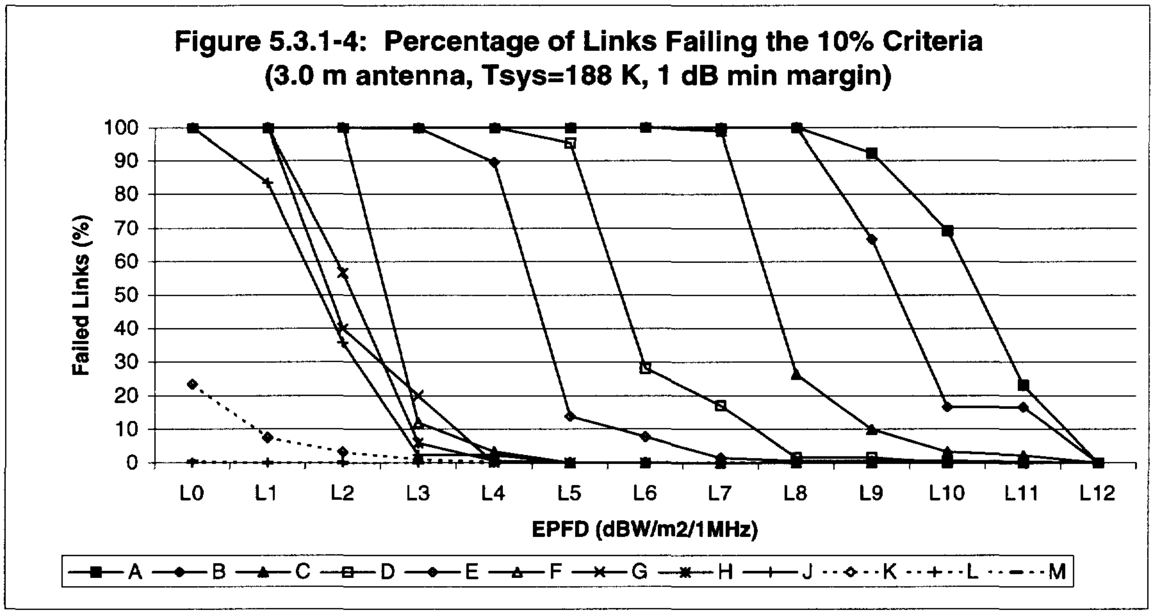
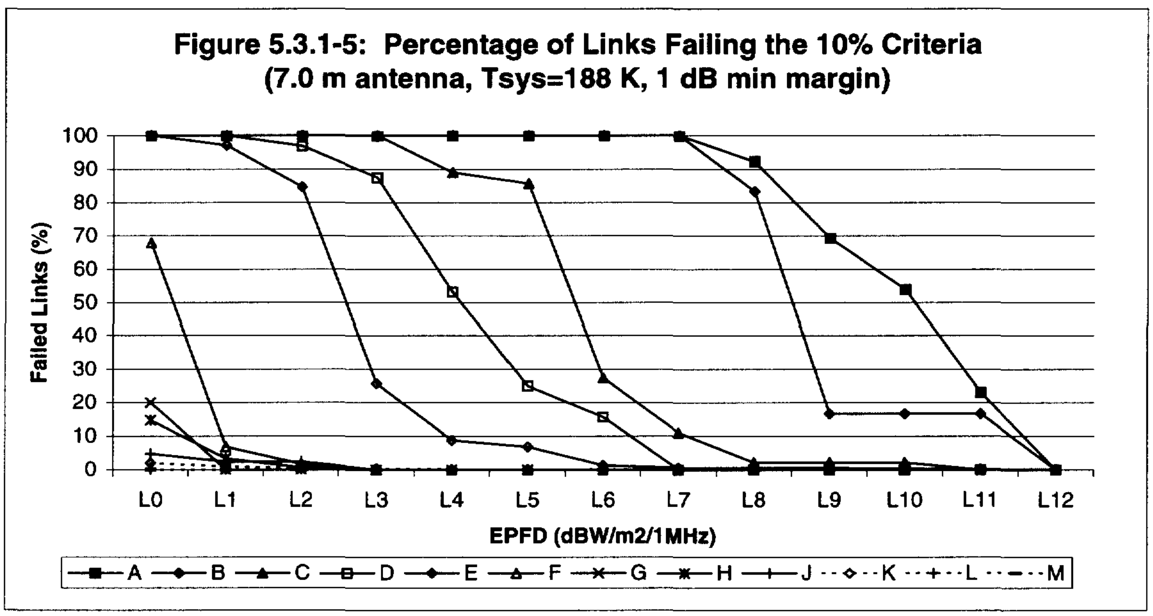


Figure 5.3.1-5 and 5.3.1-6 shows the evaluation results for a 7 m and 10 m antenna, respectively. Notice that as the antenna size increases there is a slightly slower decay from a 100 % of link failures to 0% of link failures



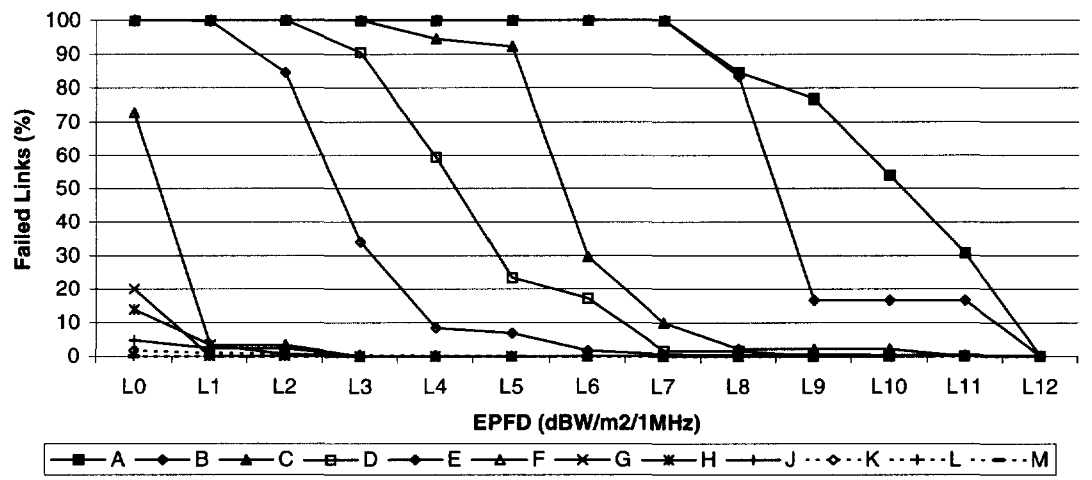


Figure 5.3.1-6: Percentage of Links Failing the 10% Criteria (10.0 m antenna, Tsys=188 K, 1 dB min margin)

5.3.2 Sensitivity in Temperature

The analysis in this section is the same as in Section 5.3.1 except that the earth station system temperature has been increased for all links by a factor of three from 188 K to 564 K. New results were then generated for the 0.6 m and 10 m earth station antennas. Table5.3.2-1 shows the epfd limits evaluated and should be used as a key to the results in Figures 5.3.2-1 to 5.3.2-2. The higher temperature was included to demonstrate the sensitivity of the analysis to this parameter.

Table 5.3.2-1: Epfd limits evaluated in Figures 5.3.2-1 to 5.3.2-2.

	EPFD	EPFD (dBW/m2/4 kHz)												
Figure	%	L0	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12
	99	-171	-172	-173	-174	-175	-176	-177	-178	-179	-180	-181	-182	-183
5.3.2-1	99.97	-161	-162	-163	-164	-165	-166	-167	-168	-169	-170	-171	-172	-173
(0.6 m)	100	-160	-161	-162	-163	-164	-165	-166	-167	-168	-169	-170	-171	-172
	99	-194	-195	-196	-197	-198	-199	-200	-201	-202	-203	-204	-205	-206
5.3.2-2	99.999	-182	-183	-184	-185	-186	-187	-188	-189	-190	-191	-192	-193	-194
(10 m)	100	-181	-182	-183	-184	-185	-186	-187	-188	-189	-190	-191	-192	-193

Figure 5.3.2-1 shows the result of the epfd evaluation for a 0.6 m antenna with a system temperature of 564 K. This result should be compared to Figure 5.3.1-1 for a system temperature of 188 K. Notice that increasing the temperature by a factor of three allows the epfd limits to be loosened by about 5 dB (from L12 to L7) such that cities in all of the rain zones pass the 10% criteria.

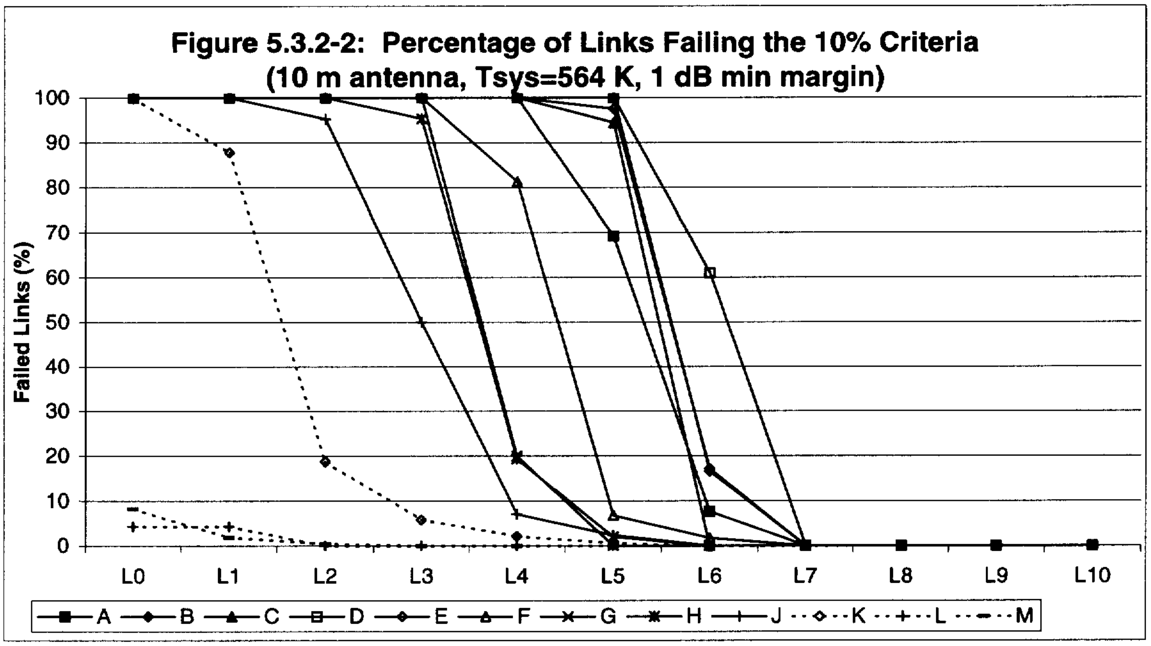
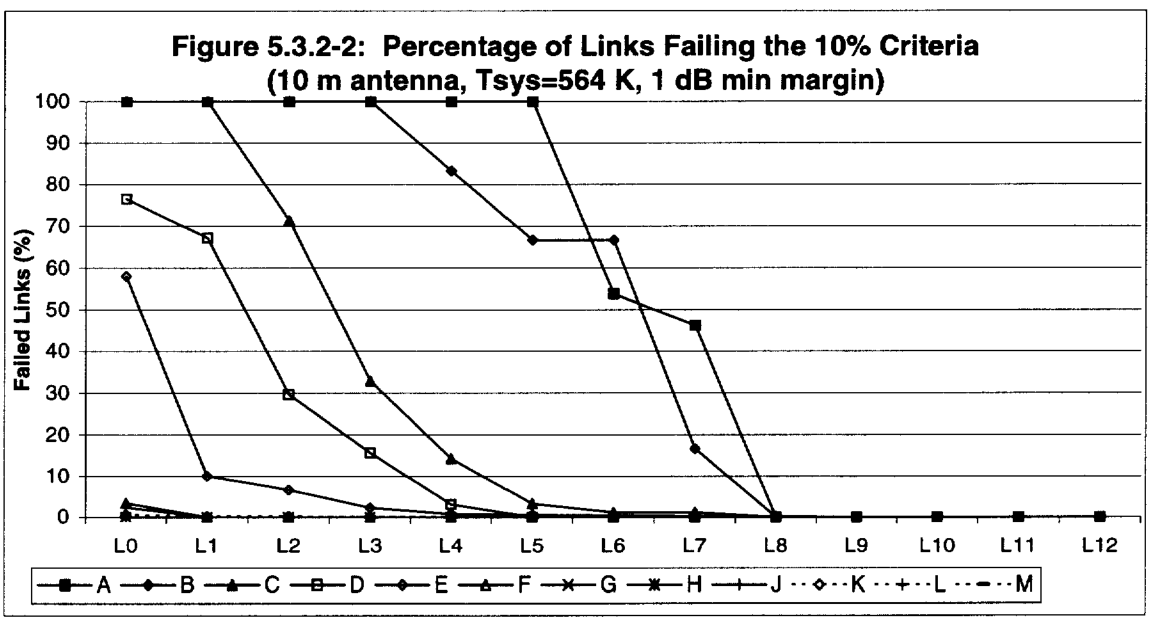


Figure 5.3.2-2 shows the result of the epfd evaluation for a 10 m antenna with a system temperature of 564 K.. This result should be compared to Figure 5.3.1-6 for a system temperature of 188 K. Notice that in this case, the increase in system temperature results in a 4 dB relaxation of the epfd limits such that all cities in all of the rain zones pass the 10% criteria.



5.3.3

5.3.4 Elevation Angle Sensitivity

The analysis in this section is the same as in section 5.3.1 except that instead of using the maximum earth station elevation angle a 20 degree nominal elevation angle was assumed. For a few locations, however, the maximum elevation angle was less than 20 degrees. These locations used a maximum elevation angle. The low elevation angle was included to demonstrate the sensitivity of the analysis to this parameter. The antennas tested were 0.6 and 10 m diameters with a system temperature of 188 K. Table 5.3.3-1 shows the epfd limits evaluated and should be used as a key to the results in Figures 5.3.3-1 to 5.3.3-2.

Table 5.3.3-1: Epfd limits evaluated in Figures 5.3.3-1 to 5.3.3-2.

	EPFD	**EPFD (dBW/m2/4 kHz)**												
Figure	%	L0	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12
	99	-171	-172	-173	-174	-175	-176	-177	-178	-179	-180	-181	-182	-183
5.3.2-1	99.97	-161	-162	-163	-164	-165	-166	-167	-168	-169	-170	-171	-172	-173
	100	-160	-161	-162	-163	-164	-165	-166	-167	-168	-169	-170	-171	-172
	99	-194	-195	-196	-197	-198	-199	-200	-201	-202	-203	-204	-205	-206
5.3.2-2	99.999	-182	-183	-184	-185	-186	-187	-188	-189	-190	-191	-192	-193	-194
	100	-181	-182	-183	-184	-185	-186	-187	-188	-189	-190	-191	-192	-193

Figure 5.3.3-1 shows the result of the epfd evaluation for a 0.6 m antenna with an elevation angle of 20 degrees. This result should be compared to Figure 5.3.1-1. Notice that changing the elevation angle reduced the final limit, required to protect all cities in all rain zones, by one dB. In general the lower elevation angle has shifted the rain zone curves to the left by 2 to 3 dB.

Figure 5.3.3-1: Percentage of Links Failing the 10% Criteria (Elevation Angle <= 20 deg, 0.6 m antenna, Tsys=188 K, 1 dB min margin)

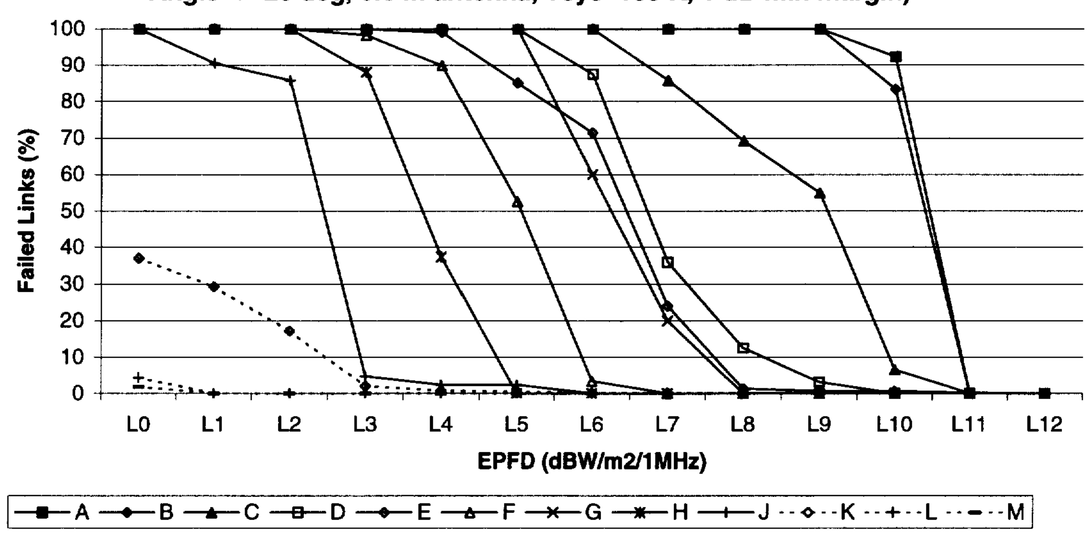


Figure 5.3.3-2 shows the result of the epfd evaluation for a 10 m antenna with an elevation angle of 20 degrees. This result should be compared to Figure 5.3.1-6. Notice that changing the elevation angle made about a 2 dB difference in the final limit requred to protect all cities in all rain zones.

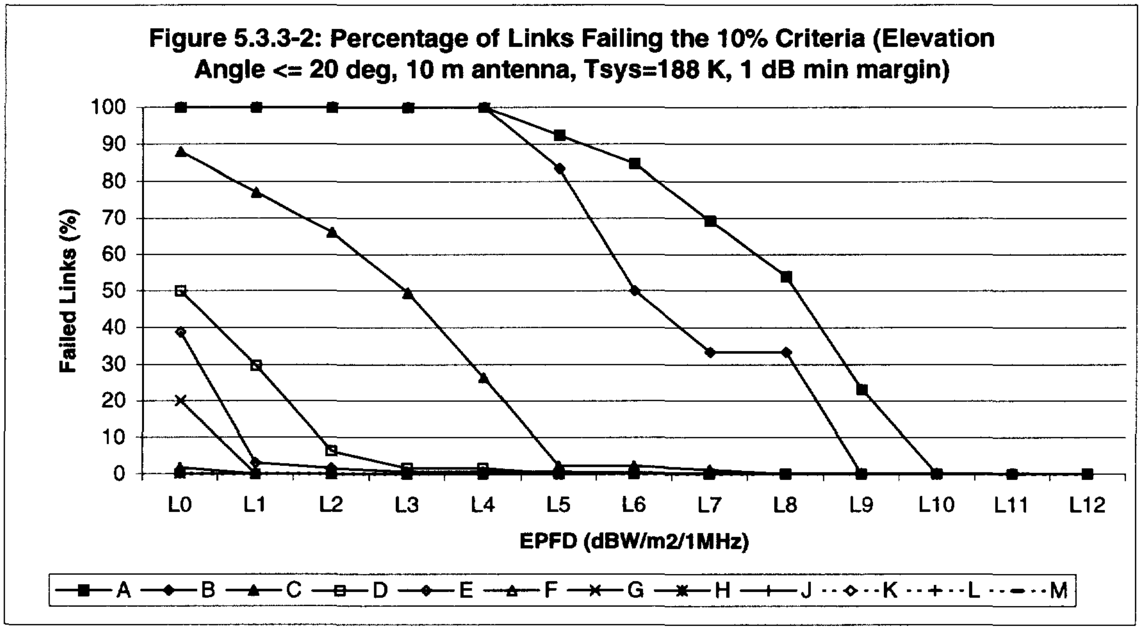


Figure 5.3.3-2: Percentage of Links Failing the 10% Criteria (Elevation Angle <= 20 deg, 10 m antenna, Tsys=188 K, 1 dB min margin)
100
90
80
70
60
50
40
30
20
10
0
Failed Links (%)
L0
L1
L2
L3
L4
L5
L6
L7
L8
L9
L10
L11
L12
EPFD (dBW/m2/1MHz)
A
B
C
D
E
F
G
H
J
K
L
M

ANNEX 1: World Urban Population Centers

Country	City	Long	Lat	Pop	RZ	Alt	Country	City	Long	Lat	Pop	RZ	Alt
China	Urumqi	87.083	43	1084060	a	1962	Russian Fed.	Murmansk	33.133	68.983	426000	c	140
China	Shihezi	86.167	44.317	563740	a	403	Russian Fed.	Nizhny_Tagil	59.967	58	423000	c	233
Saudi_Arabia	Jeddah	39.167	21.5	561104	a	105	Russian Fed.	Kirov	49.667	58.583	415000	c	135
China	Uhai	106.87	39.783	266620	a	1525	Russian Fed.	Arkhanglsk	41	64.667	412000	c	68
Russian Fed.	Petropavlovsk	158.72	53.05	248000	a	300	Russian Fed.	Cheboksary	47.2	56.133	402000	c	113
Saudi_Arabia	Riyadh	46.767	24.65	198186	a	640	Saudi_Arabia	Makkah	39.817	21.433	366801	c	335
Egypt	Aswan	32.933	24.083	196000	a	213	Russian Fed.	Ashkhabad	58.4	37.967	366000	c	200
China	Yumen	97.717	39.9	195290	a	2070	Russian Fed.	Kurgan	65.333	55.5	348000	c	128
Russian Fed.	Norilsk	88.033	69.35	181000	a	188	Russian Fed.	Chita	113.58	52.05	342000	c	730
Russian Fed.	Nakhodka	-179	71.167	152000	a	535	Russian Fed.	Makhachkala	47.5	42.983	311000	c	80
Russian Fed.	Magadan	150.83	59.633	145000	a	295	Russian Fed.	Cherepovets	37.833	59.15	309000	c	113
Russian Fed.	Stakhanov	101.67	71.767	112000	a	30	Russian Fed.	Dzhambul	71	43.167	308000	c	468
Russian Fed.	Vorkuta	64	67.45	110000	a	150	Ethiopia	Asmara	38.967	15.333	307070	c	1829
US	Salt_Lake_Cty	-111.9	40.75	1041400	b	1316	Egypt	Assyut	31.117	27.233	291000	c	52
US	Spokane	-117.4	47.667	356900	b	669	Russian Fed.	Namangan	71.683	41.391	283000	c	1400
US	Provo	-111.6	40.267	240500	b	2246	Russian Fed.	Andizhan	72	41.167	281000	c	830
China	Kuytun	85	44.5	239870	b	533	Russian Fed.	Vologda	39.917	59.167	273000	c	150
US	Ogden	-112.2	40.78	76570	b	1322	Russian Fed.	Kostroma	40.983	57.767	273000	c	105
China	Korla	86.167	41.8	117690	b	1205	UnitedArabEm	Dubai	55.283	25.233	265702	c	-1
Russian Fed.	Gorky	45.067	57.6	1409000	c	90	Egypt	Suez	32.55	29.983	265000	c	45
Russian Fed.	Sverdlovsk	60.583	56.867	1315000	c	270	Russian Fed.	Petrozavodsk	34.317	61.767	259000	c	160
Afghanistan	Kabul	69.167	34.5	1297000	c	2513	China	Yining	81.467	43.833	257280	c	1015
Iran	Mashhad	59.567	36.267	1120000	c	1088	China	Kashi	76	39.483	256890	c	1348
Russian Fed.	Chelyabinsk	61.417	55.2	1107000	c	210	Russian Fed.	Andropov	38.833	58.05	252000	c	105
Russian Fed.	Alma-Ata	76.917	43.317	1088000	c	775	Russian Fed.	Volzhsky	47.85	46.65	250000	c	-30
Russian Fed.	Perm	56.167	58.017	1065000	c	150	Russian Fed.	Bratsk	101.83	56.333	245000	c	483
Russian Fed.	Kazan	49.167	55.75	1057000	c	75	UnitedArabEm	Abu_Dhabi	54.417	24.467	242975	c	-1
Saudi_Arabia	Ta'if	40.35	21.25	666840	c	1905	Russian Fed.	Yoshkar-Ola	47.867	56.633	236000	c	60
Russian Fed.	Yaroslavi	39.867	57.567	630000	c	120	US	Anchorage	-149.8	61.167	235000	c	80

Country	City	Long	Lat	Pop	RZ	Alt	Country	City	Long	Lat	Pop	RZ	Alt
Russian Fed.	Frunze	74.833	42.667	617000	c	2113	Russian Fed.	Severodvinsk	39.833	64.566	234000	c	30
Russian Fed.	Astrakhan	48.067	46.367	503000	c	-30	Russian Fed.	Sumgait	49.633	40.583	228000	c	-30
Russian Fed.	Ivanovo	41.99	57	476000	c	120	Egypt	Faiyum	30.833	29.317	227000	c	74
Russian Fed.	Breznev	52.317	55.7	459000	c	120	Russian Fed.	Syktykar	50.75	61.7	218000	c	60
Russian Fed.	Tyumen	65.483	57.183	440000	c	60	Qatar	Doha	51.535	25.217	217294	c	30
Russian Fed.	Surgut	73.333	61.217	215000	c	90	Russian Fed.	Solikamsk	56.75	59.667	107000	c	135
Sudan	Port_Sudan	37.117	19.633	205000	c	152	Russian Fed.	Novocheboksars	47.45	56.083	106000	c	90
Russian Fed.	Zlatoust	59.633	55.167	205000	c	595	Russian Fed.	Kineshma	42.133	57.467	105000	c	120
Russian Fed.	Osh	72.817	40.617	204000	c	915	Russian Fed.	Serov	60.533	59.7	103000	c	128
Chile	Antofagasta	-70.38	-23.67	203067	c	252	Russian Fed.	Uhta	53.733	63.55	102000	c	90
Egypt	Menia	30.75	28.001	203000	c	43	UnitedArabEm	Ai-Ain	55.75	24.183	101663	c	455
Russian Fed.	Kamensk-Uralsk	61.817	56.483	202000	c	180	Saudi_Arabia	Huful	49.567	25.333	101271	c	165
Russian Fed.	Nizenvartovsk	76.667	60.95	200000	c	90	Russian Fed.	Ust-Ilimsk	102.65	58.05	101000	c	305
Russian Fed.	Fergana	71.317	40.383	199000	c	490	Russian Fed.	Votkinsk	54	57	100000	c	128
Russian Fed.	Berezniki	56.817	59.433	198000	c	120	Namibia	Windhoek	17.1	-22.57	36051	c	1829
Russian Fed.	Yakutsk	129.83	62.167	184000	c	105	Russian Fed.	Sarapul	60.967	64.25	110000	c	90
Russian Fed.	Nizhnekamsk	51.783	55.6	177000	c	90	Russian Fed.	Taldi-Kurgan	78.383	45.033	109000	c	835
Afghanistan	Herat	62.167	34.333	168200	c	988	Bahrain	Manama	50.568	26.2	108684	c	-10
Egypt	Beni-Suef	31.083	29.083	163000	c	27	Iran	Sabzewar	57.633	36.217	108000	c	958
Russian Fed.	Yuzhno-Sakhali	142.75	46.967	163000	c	120	UnitedArabEm	Sharjah	55.433	25.333	125149	c	30
Russian Fed.	Miass	60.133	55	162000	c	393	Russian Fed.	Margelan	71.75	40.5	124000	c	460
Chile	Arica	-70.29	-18.5	158422	c	308							
Sudan	Kassala	36.417	15.4	149000	c	1268							
Russian Fed.	Guryev	51.983	47.133	147000	c	-30							
Egypt	Kena	32.7	26.133	142000	c	72							
Egypt	Sohag	31.7	26.55	141000	c	64							
Yemen	Sana	44.233	15.4	140339	c	2590							
Russian Fed.	Pervouralsk	59.967	56.983	138000	c	335							
Mauritania	Nouakchott	-17.05	20.9	134986	c	5							
Saudi_Arabia	Dammam	50.1	26.417	127844	c	60							
Chile	Iquique	-70.13	-20.25	127491	c	144							

ANNEX 2: Ku epfd Link Data for 4kHz Bandwidth.

Table A2-1: Ku-band epfd limits for 0.6 m Antenna from Sensitive Links (1 dB Minimum Margin).

Fraction of Unavailability due to NGSO

Antenna	**size =0.6m**										
	% Can't Exceed	**EPFD**									
	99	*-176*	-177	-178	-179	-180	-181	-182	-183	-184	**-183**
	99.97	*-169*	-170	-171	-172	-173	-174	-175	-176	-177	**-173**
	100	*-163*	-164	-165	-166	-167	-168	-169	-170	-171	**-172**
Country	**City**										
US	Denver	0.327	0.261	0.212	0.211	0.159	0.158	0.158	0.101		
China	Urumqi	0.755	0.713	0.704	0.695	0.689	0.686	0.683			
China	Yumen	0.686	0.603	0.586	0.568	0.559	0.552	0.545			
China	Uhai	0.585	0.441	0.418	0.379	0.359	0.358	0.339			
Saudi_Arabia	Riyadh	0.609	0.475	0.438	0.420	0.403	0.386	0.368			
Russian Fed.	Nakhodka	0.605	0.470	0.431	0.413	0.395	0.376	0.359			
China	Shihezi	0.589	0.446	0.424	0.386	0.367	0.366	0.347			
Russian Fed.	Petropavlovsk	0.588	0.442	0.419	0.380	0.359	0.359	0.340			
Russian Fed.	Magadan	0.576	0.424	0.375	0.352	0.329	0.305	0.305	0.282		
Egypt	Aswan	0.558	0.405	0.361	0.335	0.310	0.285	0.284	0.258		
Russian Fed.	Norilsk	0.555	0.399	0.365	0.340	0.315	0.289	0.289	0.264		
Russian Fed.	Vorkuta	0.561	0.425	0.370	0.346	0.321	0.297	0.297	0.273		
Saudi_Arabia	Jeddah	0.531	0.391	0.309	0.275	0.242	0.241	0.208	0.207		
Russian Fed.	Stakhanov	0.660	0.559	0.538	0.527	0.506	0.497	0.497			
US	Provo	0.552	0.396	0.368	0.343	0.319	0.295	0.294			
US	Garland	0.555	0.399	0.365	0.340	0.314	0.289	0.289	0.264		
US	Salt_Lake_City	0.549	0.396	0.359	0.333	0.306	0.280	0.279	0.253		
China	Korla	0.527	0.388	0.307	0.273	0.239	0.238	0.204	0.203		
US	Spokane	0.493	0.394	0.303	0.267	0.231	0.230	0.194	0.193		
China	Kuytun	0.558	0.406	0.361	0.335	0.310	0.284	0.284	0.258		
Yemen	Sana	0.595	0.450	0.429	0.410	0.374	0.373	0.356			
Afghanistan	Kabul	0.589	0.447	0.425	0.387	0.369	0.368	0.349			
Russian Fed.	Frunze	0.486	0.407	0.300	0.262	0.224	0.223	0.185	0.184		
Saudi_Arabia	Ta'if	0.476	0.394	0.300	0.262	0.223	0.223	0.183	0.183		
Ethiopia	Asmara	0.479	0.397	0.301	0.264	0.227	0.226	0.189	0.189		
Namibia	Windhoek	0.509	0.386	0.305	0.270	0.236	0.235	0.200	0.200		
Russian Fed.	Namangan	0.482	0.400	0.302	0.265	0.228	0.228	0.190	0.190		
China	Kashi	0.419	0.325	0.257	0.211	0.210	0.160	0.159	0.159	0.110	
Sudan	Kassala	0.425	0.342	0.261	0.212	0.212	0.167	0.166	0.166		
Iran	Mashhad	0.457	0.345	0.260	0.257	0.215	0.173	0.172	0.172		
China	Yining	0.419	0.325	0.257	0.211	0.210	0.160	0.160	0.160	0.111	
Afghanistan	Herat	0.422	0.328	0.257	0.211	0.210	0.161	0.160	0.160	0.111	
Iran	Sabzewar	0.433	0.336	0.257	0.211	0.211	0.165	0.165	0.164	0.118	
Russian Fed.	Osh	0.418	0.336	0.257	0.211	0.210	0.163	0.163	0.163	0.116	
Russian Fed.	Taldi-Kurgan	0.403	0.326	0.257	0.210	0.209	0.162	0.162	0.161	0.111	
Russian Fed.	Andizhan	0.419	0.325	0.257	0.211	0.210	0.160	0.160	0.160	0.118	
Russian Fed.	Alma-Ata	0.433	0.336	0.257	0.211	0.210	0.165	0.164	0.164	0.109	
Russian Fed.	Chita	0.408	0.316	0.257	0.210	0.210	0.159	0.159	0.158		

Russian Fed.	Zlatoust	0.384	0.262	0.257	0.211	0.160	0.159	0.159	0.104	
Russian Fed.	Fergana	0.401	0.314	0.257	0.211	0.211	0.161	0.160	0.160	0.106
Russian Fed.	Bratsk	0.386	0.302	0.258	0.211	0.211	0.161	0.160	0.160	
Russian Fed.	Dzhambul	0.375	0.313	0.255	0.202	0.191	0.13	0.113		

Table A2-2: Ku-band epfd limits for 0.6 m Antenna from Sensitive Links (2 dB Minimum Margin).

Antenna	**size =0.6m**						
	%	**EPFD**					
	1	*-176*	-177	-178	-179	-180	**-181**
	0.03	*-169*	-170	-171	-172	-173	**-174**
	0	*-163*	-164	-165	-166	-167	**-168**
Country	**City**	**Fraction of Unavailability due to NGSO**					
US	Denver	0.369	0.353	0.34	0.33		
China	Urumqi	0.918	0.917	0.92			
China	Yumen	0.912	0.912	0.91			
China	Uhai	0.832	0.832	0.83			
Saudi_Arabia	Riyadh	0.726	0.723	0.72			
Russian Fed.	Nakhodka	0.776	0.773	0.77	0.13	0.104	
China	Shihezi	0.759	0.755	0.75	0.12		
Russian Fed.	Petropavlovsk	0.742	0.739	0.74	0.11		
Russian Fed.	Magadan	0.73	0.726	0.72	0.1		
Egypt	Aswan	0.684	0.677	0.67			
Russian Fed.	Norilsk	0.659	0.654	0.65	0.11		
Russian Fed.	Vorkuta	0.671	0.665	0.66	0.12		
Saudi_Arabia	Jeddah	0.679	0.673	0.67			
Russian Fed.	Stakhanov	0.567	0.56	0.55			
US	Provo	0.81	0.809	0.81			
US	Garland	0.671	0.666	0.66	0.11		
US	Salt_Lake_City	0.671	0.665	0.66	0.12		
China	Korla	0.648	0.643	0.64	0.11		
US	Spokane	0.566	0.559	0.55	0.11		
China	Kuytun	0.54	0.53	0.52	0.11		
Yemen	Sana	0.659	0.654	0.65			
Afghanistan	Kabul	0.746	0.743	0.74			
Russian Fed.	Frunze	0.741	0.738	0.74	0.11		
Saudi_Arabia	Ta'if	0.517	0.505	0.5			
Ethiopia	Asmara	0.522	0.512	0.5			
Namibia	Windhoek	0.526	0.517	0.51			
Russian Fed.	Namangan	0.548	0.537	0.53			
China	Kashi	0.53	0.52	0.51			
Sudan	Kassala	0.45	0.435	0.43	0.42		
Iran	Mashhad	0.468	0.454	0.44	0.44		
China	Yining	0.489	0.478	0.47	0.46		
Afghanistan	Herat	0.45	0.434	0.42	0.42		
Iran	Sabzewar	0.452	0.438	0.43	0.42		
Russian Fed.	Osh	0.459	0.447	0.44	0.43		
Russian Fed.	Taldi-Kurgan	0.461	0.448	0.44	0.43		
Russian Fed.	Andizhan	0.451	0.436	0.43	0.42		
Russian Fed.	Alma-Ata	0.45	0.435	0.42	0.42		
Russian Fed.	Chita	0.46	0.447	0.44	0.43		

Russian Fed.	Zlatoust	0.439	0.423	0.41	0.4
Russian Fed.	Fergana	0.403	0.388	0.38	0.37
Russian Fed.	Bratsk	0.419	0.404	0.39	0.38
Russian Fed.	Dzhambul	0.405	0.39	0.38	0.37

Table A2-3: Ku-band epfd limits for 1.2 m Antenna from Sensitive Links (1 dB Minimum Margin).

Antenna	**size =1.2m**										
	% Can't Exceed	**EPFD**									
	99	*-181*	-182	-183	-184	-185	-186	-187	-188	-189	**-189**
	99.98	*-174*	-175	-176	-177	-178	-179	-180	-181	-182	**-178**
	100	*-168*	-169	-170	-171	-172	-173	-174	-175	-176	**-177**
	Country	**City**				**Fraction of Unavailability due to NGSO**					
US	Denver	0.313	0.273	0.227	0.177	0.165	0.11				
China	Yumen	0.842	0.716	0.648	0.631	0.617	0.610	0.604	0.599		
China	Uhai	0.841	0.711	0.644	0.628	0.614	0.603	0.597	0.593		
Saudi_Arabia	Riyadh	0.784	0.643	0.536	0.512	0.492	0.474	0.464	0.454		
Russian Fed.	Nakhodka	0.677	0.558	0.408	0.366	0.335	0.315	0.295	0.276		
China	Shihezi	0.707	0.573	0.427	0.389	0.360	0.337	0.320	0.304		
Russian Fed.	Petropavlovsk	0.697	0.568	0.423	0.384	0.355	0.332	0.309	0.296		
Russian Fed.	Magadan	0.687	0.564	0.414	0.374	0.344	0.320	0.301	0.287		
Egypt	Aswan	0.679	0.559	0.408	0.371	0.339	0.316	0.295	0.281		
Russian Fed.	Norilsk	0.639	0.542	0.400	0.343	0.313	0.285	0.264	0.247	0.234	
Russian Fed.	Vorkuta	0.609	0.518	0.395	0.326	0.294	0.268	0.245	0.227	0.213	
Saudi_Arabia	Jeddah	0.617	0.527	0.395	0.331	0.295	0.271	0.247	0.234	0.221	
Russian Fed.	Stakhanov	0.632	0.541	0.398	0.339	0.305	0.281	0.258	0.242	0.229	
US	Provo	0.537	0.442	0.353	0.294	0.257	0.232	0.209	0.187	0.176	
US	Garland	0.761	0.616	0.497	0.470	0.447	0.428	0.413	0.402		
US	Salt_Lake_City	0.618	0.528	0.394	0.331	0.296	0.271	0.248	0.234	0.221	
China	Korla	0.617	0.527	0.395	0.331	0.296	0.271	0.247	0.234	0.221	
US	Spokane	0.604	0.513	0.393	0.324	0.291	0.261	0.241	0.223	0.209	
China	Kuytun	0.536	0.440	0.353	0.294	0.257	0.232	0.209	0.187	0.176	
Yemen	Sana	0.511	0.415	0.328	0.286	0.249	0.224	0.200	0.181	0.163	
Afghanistan	Kabul	0.797	0.709	0.402	0.364	0.323	0.28	0.214	0.136		
Russian Fed.	Frunze	0.806	0.725	0.399	0.362	0.321	0.25	0.215	0.136		
Saudi_Arabia	Ta'if	0.586	0.398	0.311	0.268	0.223	0.17	0.159			
Ethiopia	Asmara	0.546	0.434	0.310	0.269	0.223	0.17	0.158			
Namibia	Windhoek	0.566	0.457	0.311	0.269	0.223	0.17	0.158			
Russian Fed.	Namangan	0.582	0.451	0.313	0.272	0.226	0.18	0.160			
China	Kashi	0.583	0.476	0.311	0.270	0.224	0.17	0.161			
Sudan	Kassala	0.468	0.311	0.269	0.225	0.175	0.16	0.102			
Iran	Mashhad	0.460	0.312	0.272	0.226	0.177	0.17	0.106			
China	Yining	0.526	0.387	0.274	0.229	0.218	0.17	0.110			
Afghanistan	Herat	0.464	0.311	0.269	0.225	0.175	0.16	0.102			
Iran	Sabzewar	0.491	0.312	0.270	0.225	0.175	0.16	0.103			
Russian Fed.	Osh	0.480	0.362	0.272	0.226	0.177	0.16	0.107			
Russian Fed.	Taldi-Kurgan	0.490	0.311	0.271	0.225	0.176	0.16	0.105			
Russian Fed.	Andizhan	0.479	0.311	0.270	0.224	0.174	0.16	0.102			
Russian Fed.	Alma-Ata	0.464	0.311	0.269	0.225	0.175	0.16	0.102			

Russian Fed.	Chita	0.482	0.364	0.271	0.226	0.177	0.16	0.105
Russian Fed.	Zlatoust	0.464	0.312	0.269	0.223	0.173	0.16	0.100
Russian Fed.	Fergana	0.344	0.308	0.230	0.220	0.168	0.15	
Russian Fed.	Bratsk	0.359	0.309	0.268	0.222	0.171	0.16	
Russian Fed.	Dzhambul	0.344	0.308	0.266	0.220	0.169	0.15	

Table A2-4: Ku-band epfd limits for 1.8 m Antenna from Sensitive Links (1 dB Minimum Margin).

Antenna	**size =1.8m**										
	% Can't Exceed	**EPFD**									
	99	*-185*	-186	-187	-188	-189	-190	-191	-192	-193	**-192**
	99.99	*-176*	-177	-178	-179	-180	-181	-182	-183	-184	**-181**
	100	*-171*	-172	-173	-174	-175	-176	-177	-178	-179	**-180**
Country	**City**	**Fraction of Unavailability due to NGSO**									
US	Denver	0.269	0.226	0.185	0.137	0.117					
China	Urumqi	0.882	0.810	0.663	0.492	0.469	0.457	0.447	0.441		
China	Yumen	0.879	0.807	0.663	0.491	0.465	0.449	0.441	0.433		
China	Uhai	0.807	0.729	0.583	0.410	0.363	0.342	0.327	0.316	0.306	
Saudi_Arabia	Riyadh	0.641	0.538	0.428	0.321	0.254	0.227	0.206	0.188	0.174	
Russian Fed.	Nakhodka	0.680	0.579	0.470	0.346	0.271	0.246	0.223	0.205	0.191	
China	Shihezi	0.668	0.564	0.457	0.344	0.266	0.239	0.219	0.202	0.189	
Russian Fed.	Petropavlovsk	0.654	0.551	0.445	0.337	0.260	0.234	0.210	0.195	0.181	
Russian Fed.	Magadan	0.643	0.541	0.434	0.324	0.259	0.227	0.207	0.189	0.175	
Egypt	Aswan	0.596	0.490	0.381	0.284	0.241	0.214	0.193	0.171	0.160	
Russian Fed.	Norilsk	0.560	0.451	0.346	0.262	0.229	0.207	0.186	0.170	0.154	
Russian Fed.	Vorkuta	0.569	0.462	0.357	0.266	0.234	0.208	0.186	0.170	0.155	
Saudi_Arabia	Jeddah	0.586	0.480	0.370	0.279	0.236	0.214	0.192	0.171	0.155	
Russian Fed.	Stakhanov	0.470	0.365	0.270	0.235	0.209	0.188	0.172	0.157		
US	Provo	0.770	0.687	0.554	0.383	0.333	0.307	0.289	0.276	0.264	
US	Garland	0.570	0.464	0.358	0.266	0.234	0.208	0.186	0.170	0.155	
US	Salt_Lake_City	0.569	0.462	0.357	0.266	0.234	0.208	0.186	0.170	0.155	
China	Korla	0.553	0.445	0.341	0.261	0.228	0.207	0.185	0.165	0.154	
US	Spokane	0.470	0.364	0.270	0.235	0.209	0.188	0.172	0.157		
China	Kuytun	0.441	0.337	0.256	0.228	0.203	0.182	0.167	0.152		
Yemen	Sana	0.711	0.534	0.421	0.248	0.203	0.19	0.139			
Afghanistan	Kabul	0.819	0.690	0.595	0.328	0.253	0.21	0.156	0.129		
Russian Fed.	Frunze	0.805	0.710	0.563	0.297	0.251	0.21	0.154	0.128		
Saudi_Arabia	Ta'if	0.552	0.351	0.237	0.195	0.148	0.13				
Ethiopia	Asmara	0.514	0.302	0.238	0.196	0.180	0.13				
Namibia	Windhoek	0.552	0.332	0.239	0.197	0.180	0.13				
Russian Fed.	Namangan	0.573	0.406	0.269	0.227	0.184	0.14	0.115			
China	Kashi	0.491	0.376	0.239	0.197	0.181	0.13				
Sudan	Kassala	0.305	0.267	0.224	0.183	0.134	0.12				
Iran	Mashhad	0.402	0.271	0.228	0.185	0.139	0.12				
China	Yining	0.478	0.273	0.231	0.190	0.143	0.13				
Afghanistan	Herat	0.432	0.267	0.225	0.183	0.134	0.12				
Iran	Sabzewar	0.346	0.268	0.226	0.184	0.135	0.12				
Russian Fed.	Osh	0.382	0.270	0.227	0.186	0.139	0.12				
Russian Fed.	Taldi-Kurgan	0.407	0.269	0.226	0.185	0.137	0.12				

Russian Fed.	Andizhan	0.318	0.266	0.224	0.182	0.135	0.11
Russian Fed.	Alma-Ata	0.430	0.267	0.225	0.183	0.134	0.12
Russian Fed.	Chita	0.387	0.270	0.228	0.186	0.137	0.12
Russian Fed.	Zlatoust	0.303	0.239	0.195	0.181	0.132	
Russian Fed.	Fergana	0.290	0.232	0.191	0.144	0.126	
Russian Fed.	Bratsk	0.277	0.235	0.194	0.147	0.129	
Russian Fed.	Dzhambul	0.275	0.233	0.192	0.144	0.126	

Table A2-5: Ku-band epfd limits for 3 m Antenna from Sensitive Links (1 dB Minimum Margin).

Antenna	**size =3m**												
	% Can't Exceed	**EPFD**											
	99	*-189*	-190	-191	-192	-193	-194	-195	-196	-197	-198	-199	**-197**
	99.995	*-176*	-177	-178	-179	-180	-181	-182	-183	-184	-185	-186	**-185**
	100	*-173*	-174	-175	-176	-177	-178	-179	-180	-181	-182	-183	**-184**
Country	**City**	**Fraction of Unavailability due to NGSO**											
US	Denver	0.638	0.473	0.219	0.171	0.134							
China	Urumqi	0.972	0.925	0.885	0.853	0.826	0.736	0.582	0.362	0.302	0.292	0.285	
China	Yumen	0.968	0.922	0.883	0.850	0.825	0.729	0.575	0.359	0.294	0.286	0.279	
China	Uhai	0.904	0.869	0.840	0.799	0.703	0.596	0.475	0.296	0.212	0.200	0.191	
Saudi_Arabia	Riyadh	0.834	0.784	0.694	0.592	0.474	0.350	0.226	0.174	0.158	0.143	0.163	
Russian Fed.	Nakhodka	0.845	0.823	0.729	0.643	0.524	0.392	0.266	0.182	0.165	0.149		
China	Shihezi	0.841	0.812	0.717	0.627	0.513	0.380	0.252	0.177	0.160	0.149		
Russian Fed.	Petropavlovsk	0.837	0.798	0.706	0.609	0.494	0.366	0.241	0.175	0.159	0.148		
Russian Fed.	Magadan	0.835	0.787	0.697	0.596	0.478	0.353	0.230	0.174	0.158	0.147		
Egypt	Aswan	0.823	0.737	0.658	0.538	0.411	0.288	0.189	0.167	0.151	0.141		
Russian Fed.	Norilsk	0.794	0.705	0.612	0.503	0.372	0.250	0.176	0.160	0.149			
Russian Fed.	Vorkuta	0.803	0.712	0.623	0.512	0.380	0.257	0.181	0.161	0.150			
Saudi_Arabia	Jeddah	0.820	0.728	0.645	0.527	0.399	0.276	0.183	0.166	0.151	0.141		
Russian Fed.	Stakhanov	0.712	0.625	0.518	0.389	0.268	0.185	0.162	0.148	0.139			
US	Provo	0.883	0.852	0.827	0.747	0.664	0.537	0.405	0.275	0.188	0.175	0.163	
US	Garland	0.804	0.714	0.625	0.512	0.382	0.258	0.181	0.161	0.150			
US	Salt_Lake_City	0.803	0.712	0.623	0.511	0.380	0.258	0.181	0.161	0.150			
China	Korla	0.787	0.699	0.603	0.492	0.365	0.243	0.176	0.160	0.145			
US	Spokane	0.710	0.624	0.515	0.389	0.267	0.181	0.162	0.148	0.139			
China	Kuytun	0.688	0.585	0.477	0.358	0.236	0.176	0.157	0.147				
Yemen	Sana	0.881	0.838	0.816	0.686	0.533	0.224	0.176	0.139				
Afghanistan	Kabul	0.932	0.884	0.841	0.802	0.709	0.516	0.234	0.176	0.11			
Russian Fed.	Frunze	0.932	0.878	0.839	0.808	0.661	0.424	0.345	0.174	0.11			
Saudi_Arabia	Ta'if	0.820	0.780	0.678	0.483	0.214	0.161	0.125					
Ethiopia	Asmara	0.833	0.791	0.676	0.450	0.217	0.162	0.127					
Namibia	Windhoek	0.835	0.790	0.658	0.527	0.234	0.163	0.128					
Russian Fed.	Namangan	0.846	0.823	0.693	0.567	0.331	0.173	0.137					
China	Kashi	0.834	0.785	0.627	0.456	0.323	0.165	0.129					
Sudan	Kassala	0.814	0.659	0.501	0.222	0.170	0.133						
Iran	Mashhad	0.823	0.725	0.593	0.363	0.178	0.141						
China	Yining	0.814	0.753	0.631	0.440	0.206	0.149						
Afghanistan	Herat	0.810	0.650	0.488	0.222	0.170	0.133						
Iran	Sabzewar	0.815	0.708	0.447	0.303	0.172	0.134						

Russian Fed.	Osh	0.822	0.696	0.476	0.225	0.176	0.138
Russian Fed.	Taldi-Kurgan	0.807	0.716	0.518	0.289	0.176	0.138
Russian Fed.	Andizhan	0.801	0.686	0.540	0.250	0.169	0.133
Russian Fed.	Alma-Ata	0.809	0.648	0.485	0.221	0.170	0.133
Russian Fed.	Chita	0.824	0.700	0.485	0.238	0.176	0.138
Russian Fed.	Zlatoust	0.796	0.680	0.485	0.271	0.165	0.129
Russian Fed.	Fergana	0.736	0.571	0.450	0.205	0.149	
Russian Fed.	Bratsk	0.761	0.605	0.358	0.208	0.156	0.121
Russian Fed.	Dzhambul	0.727	0.631	0.364	0.200	0.151	

Table A2-6: Ku-band epfd limits for 7 m Antenna from Sensitive Links (1 dB Minimum Margin).

Antenna	**size =7m**											
	% Can't Exceed	**EPFD**										
	99	*-197*	-198	-199	-200	-201	-202	-203	-204	-205	-206	**-203**
	99.999	*-181*	-182	-183	-184	-185	-186	-187	-188	-189	-190	**-191**
	100	*-180*	-181	-182	-183	-184	-185	-186	-187	-188	-189	**-190**
Country	**City**	**Fraction of Unavailability due to NGSO**										
US	Denver	0.198	0.164	0.102								
China	Urumqi	1.000	1.000	1.000	1.000	0.722	0.550	0.402	0.279	0.179	0.125	
China	Yumen	1.000	1.000	1.000	1.000	0.709	0.539	0.393	0.272	0.174	0.122	
China	Uhai	1.000	1.000	0.813	0.636	0.482	0.351	0.240	0.150	0.123		
Saudi_Arabia	Riyadh	0.741	0.584	0.447	0.330	0.230	0.149	0.122				
Russian Fed.	Nakhodka	0.824	0.656	0.508	0.380	0.271	0.180	0.122				
China	Shihezi	0.796	0.632	0.488	0.363	0.257	0.169	0.123				
Russian Fed.	Petropavlovsk	0.770	0.608	0.468	0.346	0.244	0.159	0.121				
Russian Fed.	Magadan	0.748	0.590	0.452	0.333	0.233	0.151	0.120				
Egypt	Aswan	0.650	0.508	0.384	0.277	0.188	0.123					
Russian Fed.	Norilsk	0.588	0.456	0.340	0.242	0.161	0.122					
Russian Fed.	Vorkuta	0.603	0.467	0.349	0.250	0.167	0.122					
Saudi_Arabia	Jeddah	0.631	0.493	0.371	0.267	0.180	0.123					
Russian Fed.	Stakhanov	0.453	0.343	0.248	0.168	0.122						
US	Provo	1.000	0.894	0.709	0.546	0.408	0.289	0.192	0.124			
US	Garland	0.604	0.469	0.352	0.251	0.168	0.122					
US	Salt_Lake_City	0.603	0.467	0.350	0.250	0.167	0.122					
China	Korla	0.575	0.445	0.332	0.235	0.155	0.122					
US	Spokane	0.451	0.341	0.246	0.167	0.121						
China	Kuytun	0.410	0.307	0.219	0.146	0.120						
Yemen	Sana	1.000	0.695	0.501	0.22	0.2	0.121					
Afghanistan	Kabul	1.000	1.000	0.723	0.29	0.23	0.197	0.118				
Russian Fed.	Frunze	1.000	1.000	0.732	0.47	0.22	0.195	0.113				
Saudi_Arabia	Ta'if	0.463	0.237	0.234	0.16							
Ethiopia	Asmara	0.612	0.241	0.205	0.16	0.1						
Namibia	Windhoek	0.605	0.376	0.206	0.16	0.1						
Russian Fed.	Namangan	0.724	0.266	0.296	0.19	0.11						
China	Kashi	0.535	0.453	0.206	0.17	0.1						
Sudan	Kassala	0.361	0.202	0.170	0.11							
Iran	Mashhad	0.351	0.215	0.195	0.12							
China	Yining	0.518	0.223	0.199	0.14							

Afghanistan	Herat	0.264	0.232	0.169	0.1
Iran	Sabzewar	0.246	0.204	0.175	0.11
Russian Fed.	Osh	0.253	0.304	0.180	0.11
Russian Fed.	Taldi-Kurgan	0.463	0.213	0.185	0.12
Russian Fed.	Andizhan	0.332	0.208	0.169	0.12
Russian Fed.	Alma-Ata	0.244	0.213	0.168	0.1
Russian Fed.	Chita	0.254	0.208	0.181	0.11
Russian Fed.	Zlatoust	0.234	0.203	0.161	0.1
Russian Fed.	Fergana	0.215	0.192	0.133	
Russian Fed.	Bratsk	0.221	0.194	0.142	
Russian Fed.	Dzhambul	0.216	0.191	0.132	

Table A2-7: Ku-band epfd limits for 10 m Antenna from Sensitive Links (1 dB Minimum Margin).

Antenna	**size =10m**										
	% Can't Exceed	**EPFD**									
	99	*-200*	-201	-202	-203	-204	-205	-206	-207	-208	-209	**-206**
	99.999	*-185*	-186	-187	-188	-189	-190	-191	-192	-193	-194	**-194**
	100	*-183*	-184	-185	-186	-187	-188	-189	-190	-191	-192	**-193**
Country	**City**	**Fraction of Unavailability due to NGSO**									
US	Denver	0.174	0.120	0.109								
China	Urumqi	1.000	1.000	1.000	0.747	0.572	0.420	0.293	0.190	0.126	0.124	
China	Yumen	1.000	1.000	1.000	0.734	0.560	0.411	0.286	0.184	0.127	0.125	
China	Uhai	1.000	0.841	0.660	0.501	0.366	0.252	0.161	0.127	0.123		
Saudi_Arabia	Riyadh	0.607	0.464	0.344	0.242	0.157	0.125	0.122				
Russian Fed.	Nakhodka	0.678	0.528	0.396	0.282	0.190	0.128	0.122				
China	Shihezi	0.654	0.506	0.379	0.270	0.179	0.127	0.124				
Russian Fed.	Petropavlovsk	0.632	0.485	0.362	0.256	0.168	0.125	0.123				
Russian Fed.	Magadan	0.612	0.470	0.349	0.246	0.160	0.124	0.123				
Egypt	Aswan	0.526	0.400	0.291	0.199	0.127	0.123	0.120				
Russian Fed.	Norilsk	0.473	0.354	0.254	0.169	0.125	0.121					
Russian Fed.	Vorkuta	0.485	0.364	0.262	0.177	0.127	0.124					
Saudi_Arabia	Jeddah	0.510	0.387	0.280	0.191	0.127	0.124					
Russian Fed.	Stakhanov	0.356	0.258	0.177	0.125	0.122						
US	Provo	1.000	0.734	0.567	0.424	0.304	0.203	0.130	0.123	0.120		
US	Garland	0.488	0.367	0.264	0.177	0.126	0.123					
US	Salt_Lake_City	0.486	0.365	0.262	0.177	0.127	0.121					
China	Korla	0.462	0.345	0.246	0.164	0.126	0.122					
US	Spokane	0.356	0.257	0.176	0.126	0.123						
China	Kuytun	0.320	0.230	0.155	0.125	0.122						
Yemen	Sana	0.795	0.299	0.233	0.198	0.137	0.111					
Afghanistan	Kabul	1.000	0.781	0.309	0.235	0.204	0.139					
Russian Fed.	Frunze	1.000	0.780	0.449	0.344	0.202	0.136	0.11				
Saudi_Arabia	Ta'if	0.250	0.286	0.169	0.113							
Ethiopia	Asmara	0.273	0.211	0.171	0.116							
Namibia	Windhoek	0.457	0.278	0.175	0.118							
Russian Fed.	Namangan	0.444	0.223	0.194	0.133	0.109						
China	Kashi	0.258	0.292	0.178	0.122							
Sudan	Kassala	0.212	0.180	0.125	0.111							

Iran	Mashhad	0.296	0.198	0.138	0.101
China	Yining	0.229	0.203	0.150	0.114
Afghanistan	Herat	0.211	0.179	0.125	0.108
Iran	Sabzewar	0.236	0.184	0.128	0.108
Russian Fed.	Osh	0.216	0.191	0.134	0.108
Russian Fed.	Taldi-Kurgan	0.217	0.196	0.133	0.114
Russian Fed.	Andizhan	0.213	0.184	0.125	0.101
Russian Fed.	Alma-Ata	0.211	0.183	0.125	0.108
Russian Fed.	Chita	0.217	0.192	0.134	0.109
Russian Fed.	Zlatoust	0.257	0.173	0.118	0.107
Russian Fed.	Fergana	0.196	0.145	0.108	
Russian Fed.	Bratsk	0.200	0.157	0.108	
Russian Fed.	Dzhambul	0.195	0.147	0.103	

Table A2-8: Ku-band apfd limits for 3 Degree beamwidth from Sensitive Links (1 dB Minimum Margin and 99.99% Availability)

Beamwidth	**=3 degrees**							
	% Can't Exceed	**APFD**						
	100	-171	-172	-173	-174	-175	-176	**-177**
Country	**City**		**Fraction of unavailability due to NGSO**					
China	Urumqi	0.173	0.157	0.112				
China	Yumen	0.170	0.153	0.142	0.129			
China	Uhai	0.149	0.136	0.127	0.119	0.114		
Saudi_Arabia	Riyadh	0.123	0.116	0.110				
Russian Fed.	Nakhodka	0.155	0.144	0.131	0.125	0.118	0.112	
China	Shihezi	0.128	0.121	0.116	0.103			
Russian Fed.	Petropavlovsk	0.130	0.123	0.115	0.109			
Russian Fed.	Magadan	0.132	0.124	0.117	0.113			
Egypt	Aswan	0.118	0.113					
Russian Fed.	Norilsk	0.133	0.124	0.118	0.114			
Russian Fed.	Vorkuta	0.131	0.124	0.117	0.111			
Saudi_Arabia	Jeddah	0.118	0.112					
Russian Fed.	Stakhanov	0.128	0.121	0.116	0.105			
US	Provo	0.143	0.132	0.125	0.116	0.112		
US	Ogden	0.115	0.112					
US	Salt_Lake_City	0.119	0.115	0.100				
China	Korla	0.118	0.113					
US	Spokane	0.114	0.103					
China	Kuytun	0.113						
Yemen	Sana	0.118	0.112					
Afghanistan	Kabul	0.127	0.120	0.114				
Russian Fed.	Frunze	0.128	0.120	0.115	0.103			
Russian Fed.	Namangan	0.114						
China	Kashi	0.111						
China	Yining	0.103						
Russian Fed.	Chita	0.103						

Table A2-9: Ku-band apfd limits for 2 Degree beamwidth from Sensitive Links (1 dB Minimum Margin and 99.99% Availability)

Beamwidth	**=2 degrees**						
	% Can't Exceed	**APFD**					
	100	-176	-177	-178	-179	-180	**-181**
Country	**City**		**Fraction of unavailability due to NGSO**				
China	Urumqi	0.140					
China	Yumen	0.148	0.134	0.115			
China	Uhai	0.130	0.124	0.115	0.109	0.109	
Saudi_Arabia	Riyadh	0.114					
Russian Fed.	Nakhodka	0.137	0.126	0.121	0.113	0.113	
China	Shihezi	0.118	0.112				
Russian Fed.	Petropavlovsk	0.118	0.114				
Russian Fed.	Magadan	0.122	0.114	0.101			
Egypt	Aswan	0.108					
Russian Fed.	Norilsk	0.122	0.115	0.107			
Russian Fed.	Vorkuta	0.119	0.114	0.100			
Saudi_Arabia	Jeddah	0.104					
Russian Fed.	Stakhanov	0.119	0.113				
US	Provo	0.128	0.119	0.116			
US	Salt_Lake_City	0.111					
China	Korla	0.109					
Afghanistan	Kabul	0.117	0.111				
Russian Fed.	Frunze	0.118	0.112				

Table A2-10: Ku-band apfd limits for 1 Degree beamwidth from Sensitive Links (1 dB Minimum Margin and 99.99% Availability).

Beamwidth	**=1 degree**						
	% Can't Exceed	**APFD**					
	100	-181	-182	-183	-184	-185	**-186**
Country	**City**	**Fraction of unavailability due to NGSO**					
China	Urumqi	0.166	0.147				
China	Yumen	0.163	0.147	0.137	0.123		
China	Uhai	0.141	0.133	0.124	0.118	0.109	
Saudi_Arabia	Riyadh	0.118	0.113				
Russian Fed.	Nakhodka	0.151	0.137	0.129	0.121	0.113	
China	Shihezi	0.125	0.118	0.112			
Russian Fed.	Petropavlovsk	0.126	0.120	0.114			
Russian Fed.	Magadan	0.129	0.121	0.116	0.105		
Egypt	Aswan	0.116	0.108				
Russian Fed.	Norilsk	0.130	0.122	0.114	0.107		
Russian Fed.	Vorkuta	0.127	0.121	0.113	0.101		
Saudi_Arabia	Jeddah	0.115	0.104				
Russian Fed.	Stakhanov	0.124	0.118	0.113			
US	Provo	0.137	0.128	0.122	0.116		
US	Ogden	0.115					
US	Salt_Lake_City	0.117	0.111				
China	Korla	0.115	0.109				
US	Spokane	0.114					
China	Kuytun	0.106					
Yemen	Sana	0.115	0.103				
Afghanistan	Kabul	0.124	0.117	0.111			

Russian Fed.	Frunze	0.124	0.118	0.112
Russian Fed.	Namangan	0.107		
Russian Fed.	Dzhambul			

ANNEX 3

CANDIDATE INPUT EPFD LIMITS THAT PROTECT GSO FSS SYSTEMS DEVELOPED USING GENERIC TRANSMISSION PARAMETERS IN THE 10/12 GHz SHARED BANDS

The methodology presented in Documents 4A/21, 4A/TEMP/36, 4-9-11/40 and 4-9-11/103 is applied here toward proposing replacements for the WRC-97 provisional epfd limits. The methodology uses generic transmission parameters and an application of ITU-R S.1323 Method B to calculate the candidate input epfd limits. The transmission parameters used are from Document 4-9-11/Temp/29[1] and are based on the existing and future technology. Performance margins are based on defining the links that are most sensitive to interference, that is those requiring the smallest clear sky margins. With this approach most GSO systems will be protected and the flexibility to develop and implement future technology will not be inhibited. All candidate input epfd limits and percentages of time not to exceed are single entry values.

1.0 Overall Principles for Determining the Candidate Input Epfd Limits

The selection of pfd limits to protect GSO/FSS networks must take into account a generic range of link characteristics for both existing and planned networks. The limits must allow evolutionary technological improvement of GSO FSS satellite and earth station receivers, particularly at the higher frequencies.

Precedent has allowed the introduction of additional GSO networks into the allocated FSS bands without coordination provided that interference from a single network increases system noise temperatures by no more than 6%. It has been accepted through the application of ITU-R recommendations, such as ITU-R S.1323, and by system designers that a system should be designed to accept total interference from all other possible GSO/FSS networks that would result in a system noise temperature increase less than 20%.

Interference from non-GSO/FSS networks differs from that of GSO/FSS networks in that it is of a time-varying nature and not steady state as that of interfering GSO/FSS networks. Accordingly, it is reasonable to consider interference from non-GSOs to constitute two segments, that which contributes to the GSO networks during their periods of "long term" availability and that which contributes to the "short term" unavailability. On that basis, it would appear consistent to allow non-GSO/FSS networks to share spectrum with GSO networks provided that each non-GSO network will limit its effect on any GSO network system noise temperature to a system noise increase of an aggregate of 6% divided by the number of NGSO systems during the full period of "long term" link availability of the GSO network. WRC-97 chose this approach; however, it is sufficient to allow the long term percent time not to exceed to be 99.0%. Furthermore, the total effect of multiple non-GSO networks operating in the same band should not increase any GSO network's system noise temperature by more than 6% during its availability period or 99.0% of time. Therefore, the single entry increase in system noise temperature should be less than 6%

[1] In this Document the 4-9-11/Temp/29 Clear Sky Margins are revised to include the earth stations receive system noise temperature increase due to rain.

divided by the number of NGSO networks which can share the same frequency. Following further study, it may also be appropriate to reduce the percentage of time not to exceed to a value below 99.0%.

Previous studies and Recommendation ITU-R S.1323 indicate that all non-GSO networks sharing the band should contribute no more than an aggregate 10% to the "short term" link unavailability period of any GSO network. Therefore, for the single entry limits a single non-GSO network should contribute no more than 10% divided by N to the "short term" link unavailability period of any GSO network.

2.0 Methodology and Key Parameters

The methodology is based on Method B of Recommendation ITU-R S.1323. Although Method B can underestimate interference it is more accurate than current computational implementations of ITU-R S.1323 Method A which produce estimates that are sensitive to modeling assumptions needed to simplify the Method A calculations. These assumptions can produce arbitrary results which may lead to inaccurate interference estimates. Method B calculations are much easier to apply and are more consistent. Also, Method B will produce reasonably accurate estimates of permissible interference in rain regions where significant rain fades occur infrequently relative to interference events. These are the rain regions where GSO FSS systems operate with small rain fade margins and therefore are most sensitive to NGSO FSS short term interference. The transmission parameters used in this study are based on systems that operate or will operate in low rain fade regions.

Values for the epfd limits necessary to protect GSO FSS systems from single entry NGSO FSS interference are calculated in JTG 4-9-11/103 and used in the following sections to review the provisional WRC-97 epfd limits and propose new limits. The calculated values for epfd limits from JTG 4-9-11/103 are based on specific system parameters and are presented in Table 2-1. The rain fade margins and link availability values are presented in Table 2-2. Rain fade margins are calculated using the parameters presented in Table 2-3. This represents GSO FSS links most sensitive to interference and thus a worst case situation.

Table 2-1 10/12 GHz Band Parameters

Parameter	Value
Earth Station Antenna Efficiency	72%
Earth Station System Noise Temperature, Sys	150 K at 11.82 GHz
Interference from Other GSOs	20%
Permissible Downlink Long Term Interference	<6%
Percentage of Time that Long Term Interference cannot be Exceeded	99.0%
Rain Margin, M_r	Determined using ITU-R 618-5
Allowable Degradation	M_r
Percentage of Time that Allowable Degradation cannot be exceeded	1-0.1(1-A)/N where 1-A=rain outage N = number of NGSO systems, seven for this study
Margin Above Sync Loss, K	2 dB

Maximum Allowable Degradation	M_r +K or M_r+2 dB
Percentage of Time that Maximum Degradation cannot be exceeded	100%

Table 2-2 Link Availability and Rain Margin at 12 GHz

Earth Station Receive Antenna Diameter (m)	Link Availability (%)	Rain Margin (dB)	Rain Model/Region
0.6	99.7	1.0	
1.0	99.8	1.2	
1.8	99.9	1.6	
2.4	99.95	2.2	ITU-R 618-5/Denver
4.5	99.99	4.1	
10	99.99	4.1	
11	99.99	4.1	

Table 2-3 Rain Model Parameters

Parameter	Value
Rain Model	ITU-R 618-5
Satellite Location	101 W deg.
City/ITU Region	Denver(USA)/E
Altitude	1.61 Km
Latitude	39.73 N deg
Longitude	104 W deg.
Elevation Angle	43.2 deg.

The value for N, the number of NGSOs that can share a frequency band, is seven. This value is based on the number of operators that have applied to the US administration for NGSO networks. It is expected that the same number or more will apply for Ku-band networks when the US administration opens a filing window. Also, Doc 4-9-11/133 has demonstrated that at least seven NGSO FSS systems can operate co-frequency using spatial isolation.

The methodology is summarized as follows.

Input Data

1) Link availability (A) requirement for each terminal antenna size
2) Location of terminal and satellite
3) Rain region or city to be served

Steps

1) Calculate the rain fade margin (M_r) required to meet the link availability for a particular link. This term is equivalent to z_t of ITU-R S.1323 Method B since the difference between clear sky C/N and required C/N is the margin needed to overcome rain fades.
2) Determine the unavailability (1-A) as the percentage of the year that the BER can exceed the required BER. This is equivalent in Method B to p, the percent of year[2] that a required BER can be exceeded.
3) Calculate the percent of time not to exceed an interference level for a given terminal size and availability as,

   1-(0.1/N)(1-A)
   Where N= number of NGSO satellite systems
   N=7 in this study

   This is the allowable outage that an NGSO FSS system can contribute to the link outage of the GSO FSS as described in Method B.
4) Relate M_r to the degradation that when exceeded results in an outage which adds to the unavailability of the satellite link, and therefore cannot be exceeded more than 1-(0.1/N) (1-A).
5) Either by applying equation 1 of Document 4-9-11/103-E Annex D or using the data provided in Tables 2-1 through 2-3, the degradation for an apfd or epfd value can be determined and associated with the calculated percent of time that the degradation (rain margin, M_r) cannot be exceeded.

Section 6 of Document 4-9-11/103-E Annex D provides a detailed description of this methodology and presents example results for long term, short term, and never to exceed epfd limits.

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[2] The S.1323 Method B "p" is based on a time interval of a year. Satellite systems can adjust power to obtain seasonal rain margins. In some cases it may be appropriate to use p, or link availability, to be based on a month time interval.

3.0 Summary of Candidate Input PFD Limit Calculation for the 10/12 GHz Frequency Bands

Using the above principles and the methodology of Document 4-9-11/103-E Annex D, epfd limits that protect GSO FSS networks for the downlink were generated. The limits generated are single entry assuming seven NGSO FSS systems. Each epfd limit is based on the $\Delta T/T$ (noise degradation) interference criterion that is associated with a percent of time not to exceed. Link parameters such as system noise temperature, percentage of noise from other GSO networks, and antenna efficiency are presented. Epfd limits were calculated for a range of earth antenna diameters. G/T values are presented for each antenna diameter for epfd.

4.0 Candidate Input NGSO FSS 10/12 GHz epfd Limits

Values for NGSO FSS epfd limits were determined using the method described in Document 4-9-11/103-E Annex D and the parameters presented in Tables 2-1 through 2-2. These epfd limits are presented in Annex 3-A based on a long term aggregate interference criterion of 6%. The short term limits were calculated, according to the methodology of Document 4-9-11/103-E, using the link margins and link availability presented in Table 2-2. The limits presented are for single entry interference only, and are proposed as NGSO FSS epfd limits to replace the limits accepted on a provisional basis by WRC-97.

Table 4-1 summarizes the candidate input epfd limits contained in Annex 3-A and compares them to the provisional epfd limits from WRC-97 Resolution 130. The candidate input limits are those necessary to adequately protect GSO FSS systems from single entry NGSO FSS interference, under the assumptions made in Section 2. Most of the WRC-97 provisional limits fail to provide sufficient protection.

Table 4-1 Candidate Input vs. Provisional 10/12 GHz Frequency Band epfd Limits

Frequency Band (GHz)	WRC-97 Provisional EPFD Limits			Candidate Input EPFD Limits for Aggregate (N=1) Case
	epfd dB(W/m^2/4KHz)	Percent of Time Not to Exceed (%)	Antenna Diameter (m)	From Table 3-A1 (for % of time not to exceed)
10.7-11.7	-179	99.7	0.6	- 176(99)
11.2-12.2 (Region 2)	-192	99.9	3	- 189(99)
	-186	99.97	3	- 189(99)
12.2-12.5 in Region 3	-195	99.97	10	- 200(99)
	-170	99.999	0.6	-163(100)
12.5-12.75 in Regions 1 and 3	-173	99.999	3	-176(99.995)
	-178	99.999	10	-185(99.999)
	-170	100	≥0.6[1]	-183(100)[1]

Note 1: The antenna size considered ranges from diameters of 0.6 m to 11 m. To determine the epfd limits the 11 m diameter antenna is used. The WRC-97 specification is not consistent with the need to protect 11 meter antennas as a case greater than 0.6 meter, and so fails to protect GSO FSS systems using larger antennas from NGSO FSS interference.

7.0 Summary

This study uses a methodology which is an application of ITU-R S.1323 Method B to determine interference criteria and thus calculate NGSO FSS epfd limits necessary to adequately protect GSO FSS systems from single entry interference caused by NGSO networks. Also, this methodology allows an assessment of GSO FSS noise degradation that would result from each of the WRC-97 provisional epfd limit values. Generic satellite transmission parameters are used to provide protection of a broad range of GSO FSS systems. Through the use of generic parameters GSO FSS system operation and implementation flexibility are maintained.

Table 3-A1 of Annex 3-A presents candidate input epfd limits that sufficiently protect GSO FSS systems from NGSO FSS interference for the aggregate (N=1) case, while Tables 3-A2 through 3-A4 present representative epfd limits assuming N=3, 5, and 7, respectively.

Annex 3-A

12 GHz epfd Limits

The following Tables present NGSO FSS epfd limits calculated using the methodology presented in Document 4-9-11/103-E Annex D.

Table 3-A1
Candidate Input Downlink epfd Limits on NGSO FSS to Protect GSO FSS for N=1 (Aggregate) at 11.7 to 12.2 GHz

Earth Station Receive Antenna Size (m)	epfd Limit on NGSO to Protect GSO dB(W/m^2/4KHz)	Percent of Time Value is Not to be Exceeded (%)
0.6	-176	99.0
1.0	-181	99.0
1.2	-181	99.0
1.8	-185	99.0
2.4	-187	99.0
3.0	-189	99.0
4.5	-192	99.0
7.0	-197	99.0
10	-200	99.0
11	-200	99.0
0.6	-169	99.97
1.0	-172	99.98
1.2	-174	99.98
1.8	-176	99.99
2.4	-176	99.995
3.0	-176	99.995

4.5	-178	99.999
7.0	-181	99.999
10	-185	99.999
11	-186	99.999
0.6	-163	100
1.2	-168	100
1.8	-171	100
3.0	-173	100
7.0	-180	100
10	-183	100
11	-183	100

Table 3-A2
Representative Downlink epfd Limits on NGSO FSS to Protect GSO FSS for N=3
at 11.7 to 12.2 GHz

Earth Station Receive Antenna Size (m)	epfd Limit on NGSO to Protect GSO dB(W/m^2/4KHz)	Percent of Time Value is Not to be Exceeded (%)
0.6	-180	99.0
1.0	-185	99.0
1.8	-189	99.0
2.4	-192	99.0
4.5	-197	99.0
10	-204	99.0
11	-207	99.0
0.6	-169	99.99
1.0	-172	99.993
1.8	-176	99.997
2.4	-176	99.998
4.5	-178	99.9997
10	-185	99.9997
11	-186	99.9997
0.6	-163	100
1.8	-174	100
11	-183	100

Table 3-A3
Representative Downlink epfd Limits on NGSO FSS to Protect GSO FSS for N=5
at 11.7 to 12.2 GHz

Earth Station Receive Antenna Size (m)	epfd Limit on NGSO to Protect GSO dB(W/m^2/4KHz)	Percent of Time Value is Not to be Exceeded (%)
0.6	-182	99.0
1.0	-187	99.0
1.8	-192	99.0
2.4	-194	99.0
4.5	-199	99.0
10	-206	99.0
11	-207	99.0
0.6	-169	99.994
1.0	-172	99.996
1.8	-176	99.998
2.4	-176	99.999

4.5	-178	99.9998
10	-185	99.9998
11	-186	99.9998
0.6	-163	100
1.8	-174	100
11	-183	100

Table 3-A4
Representative Downlink epfd Limits on NGSO FSS to Protect GSO FSS for N=7
at 11.7 to 12.2 GHz

Earth Station Receive Antenna Size (m)	epfd Limit on NGSO to Protect GSO dB(W/m^2/4KHz)	Percent of Time Value is Not to be Exceeded (%)
0.6	-184	99.0
1.0	-188	99.0
1.8	-193	99.0
2.4	-195	99.0
4.5	-201	99.0
10	-208	99.0
11	-208	99.0
0.6	-169	99.996
1.0	-172	99.997
1.8	-176	99.999
2.4	-176	99.9993
4.5	-178	99.9999
10	-185	99.9999
11	-186	99.9999
0.6	-163	100
1.8	-174	100
11	-183	100

ANNEX 4

CANDIDATE INPUT APFD LIMITS THAT PROTECT GSO FSS SYSTEMS DEVELOPED USING GENERIC TRANSMISSION PARAMETERS IN THE 12/14 GHz SHARED BANDS

The methodology presented in Documents 4A/23-E, 4-9-11/40 and 4-9-11/103 is applied here toward reviewing and proposing replacements for the WRC-97 provisional apfd limits. The methodology uses generic transmission parameters and an application of ITU-R S.1323 Method B to calculate the candidate input apfd limits. The transmission parameters used are based on the existing and future technology and presented in Document 4-9-11/Temp/23. All candidate input apfd limits are single entry values.

1.0 Overall Principles and Methodology for Determining the Candidate Input Apfd Limits

Precedent has allowed the introduction of additional GSO networks into the allocated FSS bands without coordination provided that interference from a single network increases system noise temperatures by no more than 6%. It has been accepted through the application of ITU-R recommendations, such as ITU-R S.1323, and by system designers that a system should be designed to accept total interference from all other possible GSO/FSS networks that would result in a system noise temperature increase less than 20%. In Article S22 of the Radio Regulations and Resolution 130 apfd limits are associated with a percentage of time during which the apfd level may not be exceeded of 100%. On the bases of this consideration and the GSO network interference level precedent, it would appear consistent that uplink interference should not exceed 6% of the system noise temperature for 100% of the time. In order to limit the impact of uplink interference on the downlink, the uplink interference criteria should not exceed the downlink interference limit.

The methodology and equations used to calculate apfd values is presented in Document 4-9-11/103-E Annex D. The methodology is based on Method B of Recommendation ITU-R S.1323.

Values for the apfd limits necessary to protect GSO FSS systems from single entry NGSO FSS interference are calculated in JTG 4-9-11/103 and used in the following sections to review the provisional WRC-97 apfd limits and propose new limits. The calculated values for apfd limits from JTG 4-9-11/103 are based on specific system parameters and are presented in Table 1-1.

The calculations assume a value for N, the number of NGSOs that can share a frequency band, of seven. This value is based on the number of operators that have applied to the US administration for NGSO networks. It is expected that the same number or more will apply for Ku-band networks if the US administration opens a filing window. Therefore, the uplink interference from any one NGSO system should not exceed 6/N% of the system noise temperature for 100% of the time. For N=7, this level is approximately 0.9%.

Table 1-1 12/14 GHz Band Parameters

Parameter	Value

Satellite Antenna Efficiency	62%
Satellite System Noise Temperature, T_{sys}	500K
Permissible Uplink Long Term Interference, $\Delta T/T$	<6%
Maximum Allowable Uplink Degradation	<0.25 dB

2.0 Summary of Candidate Input PFD Limit Calculation for the 12/14 GHz Frequency Bands

Using the above principles and the methodology of Document 4-9-11/103-E Annex D, apfd limits that protect GSO FSS networks for the uplink were generated. The limits generated are single entry assuming seven NGSO FSS systems. The apfd limits were calculated for a receive noise temperature of 500°K and a range of satellite receive antenna gains. Link parameters such as system noise temperature, percentage of noise from other GSO networks, and antenna efficiency are presented. G/T values are presented for each beamwidth for apfd. Although currently 12/14 GHz one degree satellite beams are not typical, today's technology can produce GSO FSS satellites with multiple beams with one degree coverage using on board signal processing. The apfd limits that are to protect GSO FSS networks should take into account beamwidths of one degree so as not to constrain the application of these smaller beamwidths.

3.0 Candidate Input NGSO FSS 12/14 GHz apfd Limits

Values for NGSO FSS apfd limits were determined using the method described in Document 4-9-11/103-E Annex D and the parameters presented in Table 1-1. These apfd limits are presented in Annex 4-A based on an aggregate interference criterion of 6% increase in system noise temperature. The limits presented are for single entry interference only, and are proposed as NGSO FSS apfd limits to replace the limits accepted on a provisional basis by WRC-97.

WRC-97 designated provisional apfd limits specified in RR S22.5 but did not specify the beamwidth to be used when determining the interference into a GSO FSS satellite receiver. 12/14 GHz GSO satellites must be protected for a variety of coverage's which require a range of beamwidths. Annex 4-A presents apfd limits necessary for adequate protection of GSO FSS systems from NGSO FSS uplink interference, for GSO satellite beamwidths of 1, 2, 3, and 5 degrees.

4.0 Summary

This study uses a methodology which is an application of ITU-R S.1323 Method B to determine interference criteria and thus calculate NGSO FSS apfd limits necessary to adequately protect GSO FSS systems from single entry interference caused by NGSO networks. Also, this methodology allows an assessment of GSO FSS noise degradation that would result from each of the WRC-97 provisional apfd limit values. Generic satellite transmission parameters are used to provide protection of a broad range of GSO FSS systems. Also, through the use of generic parameters GSO FSS system operation and implementation flexibility are maintained.

Table 4-A1 of Annex 4-A presents candidate input apfd limits that sufficiently protect GSO FSS systems from NGSO FSS interference for the aggregate (N=1) case, while Tables 4-A2 through 4-A4 present representative apfd limits assuming N=3, 5, and 7, respectively.

Annex 4-A
14 GHz APFD Limits Using Criterion of DT/T of 6%

The following Tables present NGSO FSS apfd limits calculated using the methodology presented in Document 4-9-11/103-E Annex D.

Table 4-A1
Candidate Input Uplink apfd Limits on NGSO FSS to Protect GSO FSS for N=1 (Aggregate) at 13.75 to 14.5 GHz

Satellite Receive Antenna Beamwidth (degrees)	apfd Limit on NGSO to Protect GSO dB(W/m^2/4KHz)	Percent of Time Value is Not to be Exceeded (%)
1	-166	100
2	-151	100
3	-156	100
5	-163	100

Table 4-A2
Representative Uplink apfd Limits on NGSO FSS to Protect GSO FSS for N=3 at 13.75 to 14.5 GHz

Satellite Receive Antenna Beamwidth (degrees)	apfd Limit on NGSO to Protect GSO dB(W/m^2/4KHz)	Percent of Time Value is Not to be Exceeded (%)
1	-182	100
2	-176	100
3	-172	100
5	-168	100

Table 4-A3
Representative Uplink apfd Limits on NGSO FSS to Protect GSO FSS for N=5 at 13.75 to 14.5 GHz

Satellite Receive Antenna Beamwidth (degrees)	apfd Limit on NGSO to Protect GSO dB(W/m^2/4KHz)	Percent of Time Value is Not to be Exceeded (%)
1	-184	100
2	-178	100
3	-175	100
5	-170	100

Table 4-A4
Representative Uplink apfd Limits on NGSO FSS to Protect GSO FSS for N=7
at 13.75 to 14.5 GHz

Satellite Receive Antenna Beamwidth (degrees)	apfd Limit on NGSO to Protect GSO dB(W/m^2/4KHz)	Percent of Time Value is Not to be Exceeded (%)
1	-186	100
2	-180	100
3	-176	100
5	-172	100